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MANUFACTURE OF DRY WINES IN HOT COUNTRIES.

By FREDERIC T. BIOLETTI.

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MANUFACTURE OF DRY WINES IN HOT COUNTRIES.

By FREDERIC T. BIOLETTI.

[This bulletin is the outcome of a recent visit, made under the auspices of the University, to some of the chief vine-growing regions of Europe and Algeria.

This visit was undertaken during the months of October, November, and December, 1904, and its main object was to study the many changes which have been introduced in recent years into French methods of grape-growing and wine-making. As it was impossible, in the time available, to cover the whole of the ground thoroughly, my attention was directed mainly to those subjects which seemed of most immediate interest to the University and to the committee of California grape-growers who contributed part of the necessary expenses of the trip.

In accordance with this idea, my observations had to do chiefly with the methods of wine-making peculiarly adapted to hot climates, and with the methods of viticultural and œnological education in vogue in France. Other matters of interest to Californian viticulture were given as much attention as was possible without interfering with these two main objects.

The principal educational institutions visited were the "Kgl. Lehranstalt für Wein, Obst und Gartenbau" at Geisenheim on the Rhine, the "Institut Nationale Agronomique" at Paris, the "École Nationale de Grignon" near Versailles, the "École Nationale de Montpellier" in the south of France, and the "École Pratique d'Agriculture d'Écully" near Lyons. At all of these, especial attention is given to instruction in viticulture and œnology.

Experiment stations and research laboratories devoted more or less exclusively to the same subjects were visited at Nancy, Epernay, Villefranche, Nimes, Montpellier, Narbonne, Perpignan, Toulouse, Bordeaux, and Algiers. Visits were made to the departmental professors of agriculture at these centers and to vineyards and cellars in the Rheingau, Champagne, Burgundy, Beaujolais, Côtes du Rhone, Hérault, Gard, Narbonnais, Roussillon, Médoc, and Algeria; the greater part of the time being spent in the Midi and in Algeria. My investigation was very much facilitated by the great courtesy and assistance received everywhere from investigators and proprietors. My thanks are especially due, among many others to: Professor Dr. Wortmann, Director of Geisenheim; M. Pierre Viala, Inspecteur Général de la Viticulture at Paris; M. L. Ravaz, Professor of Viticulture at Montpellier; and M. Roger Marès, Departmental Professor of Agriculture at Algiers.

I was much assisted in my investigations by the advice and encouragement of members of the California Viticultural Club, notably of Messrs. Percy L. Morgan and Frank T. Swett, without whose aid the scope of the work would have been very limited.]

INTRODUCTION.

It is a remarkable but well-recognized fact that in the regions where the vine flourishes best, that is, where it yields the maximum crop for the minimum labor, the greatest difficulties are encountered in the manufacture of sound dry wines. In a general way it may be said that nearly all the fine dry wines of the world are produced in regions such as those of the Gironde, Burgundy, and the Rhine, where the climate is relatively cool and where the vine does not attain its fullest develop-

ment either of growth or of crop. In the warmer and more productive regions, if wines of superior quality are made they are usually sweet or of sherry type. The *dry* wines of these regions are of two general types, (*a*) thin watery wines, such as those of the south of France, whose main value lies in their cheapness, and (*b*) heavy, coarse wines valuable for blending, such as those imported into France in large quantities from Spain, Algeria, and elsewhere. The wines of the latter type are not only defective in quality, but very commonly unsound, and large quantities, in the aggregate, spoil before they reach the hands of the wine merchant and become a total loss or are made into inferior brandy. This loss would be much greater but for the use of the antiseptics which are freely employed wherever the practice is not prevented by effective pure-food laws. Before discussing the question as to whether the wines of the warmer regions can be improved, and, if so, what are the most practical methods, a clear understanding of the nature of their defects and the causes of these defects is necessary.

The quality of a wine depends on two groups of factors: (*a*) those which have to do with the nature of the raw material, that is, the character of the grapes; and (*b*) those which have to do with the way in which this raw material is treated, that is, the character of the methods of manufacture. Each of these groups of factors influences the other, so that it is often difficult to decide whether certain qualities of a wine are due to the character of the grapes, or to the way in which they have been handled in the process of manufacture. For example, a wine is deficient in color: this may be due either to a lack of coloring matter in the grape or to an imperfect method of manufacture which has failed to properly utilize the coloring matter present. Again, if a wine is spoiled by bacterial fermentation, the cause may lie in careless, uncleanly methods of manufacture, or in a lack of due acidity in the grapes, which favored the growth of bacteria. In this way nearly all the qualities of a wine are influenced, both by the character of the raw material and by the method of manufacture; and a defect in either may often be neutralized to a great extent by a corresponding change in the other.

The relative importance of these groups of factors is a matter on which the opinion of wine-makers has been greatly modified during the last ten or fifteen years. Formerly, the first group was considered of overwhelming importance and certain regions were considered totally unfit for the production of sound dry wine, on account of the supposed unsuitable nature of the grapes grown there. Yet many of these regions produced the finest, largest, and best flavored table and raisin grapes. Now, while the qualities desirable in an eating grape are not the same as those necessary for a wine-making grape, there is no doubt that the main reason for the failure to produce good dry wines in the plains of

Algeria or the San Joaquin Valley does not lie in the qualities, either negative or positive, of the grapes, but *in the attempt to make wines in a hot climate by methods suited only to a cool one.*

It is worthy of note that in the regions that have been famous for the production of fine wines, such as Médoc, Rheingau, and Burgundy, the finest and highest-priced wines are produced on warm, dry hill slopes, and in years when the summer is exceptionally warm and dry. This is equivalent to saying that the finest wines of these regions are produced in situations where the soil conditions approach most nearly to those of California vineyards, and in seasons when the weather during the growing and ripening period of the grape approaches most nearly to the California climate. In fact, the more nearly the chemical composition of the grapes of the Rhine and the Gironde approaches that of California grapes, the higher the quality of the wine and the higher the price it brings in the market. Yet it is perfectly true that it is only exceptional and apparently accidental when our California wines equal or approach the quality of the best wines of the above regions.

If the composition of the raw material is approximately the same, the quality of the manufactured material ought not to differ much unless the conditions of manufacture are different. It is doubtless in the failure to make these conditions identical or equivalent that the chief difficulty lies. The use of the same methods does not result in realizing the same conditions in a hot climate as in a cool one, and whatever the summer temperature of the Gironde may be, the temperature of the autumn, when wine-making takes place, is always very much cooler than it is here. Many of the defects of our wines which were supposed to be due to inherent faults of the grapes have been shown to be due to bacterial and defective yeast fermentation, and to be completely under the control of a suitable method of wine-making. This does not mean that the locality where the grapes are grown is without influence, or that it will ever be possible to produce a Château Lafitte or a Schloss Johannisberg in Hérault or Tulare. It does mean, however, that wherever grapes mature a perfectly sound wine of good quality can be made, and that *throughout the great central plain of California sound dry wines can be produced in unlimited quantities, superior in quality to the great bulk of European wines.*

The average sugar-contents of the grapes of the plains of southern France will probably not exceed 16%, while that of the grapes of the San Joaquin will be approximately 20%. There is a corresponding superiority in other ingredients such as body and tannin; in everything, in fact, except acidity and perhaps color. The first of these defects can be remedied legitimately and without any great expense artificially, while the second can be minimized by proper methods of wine-

making and by a suitable choice of varieties. Taking these facts into consideration, then, 16 tons of grapes in the San Joaquin Valley are about the equivalent for wine-making purposes of 20 tons in the plains of the Midi. The importance of this is proved by the many attempts being made to increase the alcoholicity of the wines of southern France,* and by the fact that the most effective method at present seems to be a partial concentration of the grapes, by which 20% or 30% of the water is evaporated before they are made into wine. This is equivalent to a reduction in volume of 20 tons to 16 or 14 tons. By this means, from 20 tons of grapes is made about 2,400 gallons of full-bodied wine, suitable for export or blending, having say 12% of alcohol, instead of 3,200 gallons of thin, weak "vin ordinaire," with only 9% of alcohol. With a corresponding 20 tons of Fresno grapes it should be possible to make, without the expense of concentration, 3,200 gallons of wine equal in quality to the 2,400 made from the same quantity of French grapes. That this has not been done, or done only exceptionally and accidentally, is, I believe, *not the fault of the grapes, but of the methods of manufacture.* Much of the dry wine which it is attempted to make in the hot interior valleys of California spoils before it ever reaches the consumer, or more usually is distilled or metamorphosed into an inferior sweet wine. The dry wine at present made in this region is to a great extent of very inferior quality, deficient in normal acidity, tannin, color, aroma, and showing various defects, cloudiness, acetic and butyric acid, mannite, etc., due to bacterial or other improper fermentations. This state of things is so well recognized that most wine-makers of the San Joaquin Valley have ceased to attempt to make dry wine and turn all their grapes into the sweet wines for which the region is so specially adapted.

The crisis to which the sweet-wine market is subject in years of heavy production would be modified if it were possible to turn a certain part of the grape crop into dry wine. Many of the varieties of grapes planted in the great valleys are moreover more suited to the production of dry wines than of sweet. If the making of dry wine is to pay, however, the results must be more under the wine-maker's control and the quality must be higher than it has been in the past.

With regard to the certainty of control it is my firm belief that *there is no region in the world where the wine-maker can be so sure of making every year a good, sound, dry wine of uniform quality as in the great central plain of California.* An opinion so opposed to the practical results of the past was not arrived at without careful consideration, and is based principally upon the methods and tendencies of modern

* "What we need to satisfy our markets is alcoholic, heavy-bodied, deeply colored wines such as are not produced by our modern methods of intensive cultivation." "La Concentration des Vins," by L. Roos, Bordeaux, 1902.

wine-making in Algeria and southern France and on the long and careful tests conducted for many years by the Agricultural Experiment Station of the University of California at the Fresno, Tulare, Amador, and San Luis Obispo substations and the viticultural cellar and laboratories at Berkeley. To attain this desired result, however, requires very considerable changes in the present methods of wine-making, and in the course of this report an attempt will be made to show the essential features of this necessary change.

The conditions upon which the quality of wine depend are:

First—Those which affect the nature of the raw material, viz.: variety of grape, climate, soil, methods of cultivation (including pruning, fertilizing, etc.), vine diseases, time of gathering.

Second—Those which depend on the methods of manufacture. These methods may affect the wine in a great variety of ways. They may modify its composition by means of the addition of various substances which occur naturally in the grape, such as sugar, water, tartaric acid, and tannin, or even of substances which do not occur there in appreciable quantities naturally, such as citric acid and plaster. They may cause a more or less perfect utilization of the substances in the grape, and in this way control to a great extent the amount of color and tannin, and even of alcohol and acid in the resulting wine.

It is in the control of the fermentation, however, that the methods of manufacture have the most scope for affecting the quality of the wine for good or ill. The character of the fermentation depends on four main factors: (*a*) the composition of the grape; (*b*) the kind and number of micro-organisms (yeasts, molds, and bacteria) present; (*c*) the temperature of the fermenting mass; and (*d*) the amount of aëration.

In accordance with these facts, the attempts at finding a solution to the problem of the manufacture of sound, dry wine of good quality in hot climates have been made along different lines, which are discussed in the remaining portion of this bulletin.

METHODS FOR IMPROVING MANUFACTURE OF DRY WINES IN HOT CLIMATES.

A. *Amelioration of the character of the raw material.*
   1. Suitable varieties of grapes.
   2. Appropriate methods of cultivation.
   3. Time of gathering grapes.
   4. More complete utilization of the substances in the grapes.
   5. Addition of substances deficient in the grapes.
   6. Addition of substances not found normally in the grapes.

B. *Control of fermentation.*
   (I) By modifying the temperature.
      1. Cooling devices (physical).
      2. Cooling devices (chemical).
      3. Postponement of fermentation until winter.
      4. Fermentation in a cool locality.
         (*a*) Transportation of grapes.
         b) Transportation of crushed grapes or must.
         (*c*) Concentration of grapes for transportation.
         (*d*) Drying grapes for transportation.
   (II) By controlling the kind of fermentative agents present.
      1. Sterilization (physical).
      2. Sterilization (chemical).
      3. Pure and selected yeasts.

AMELIORATION OF THE CHARACTER OF THE RAW MATERIAL.

VARIETIES OF GRAPES.

The proper choice of varieties of grapes to plant is the first essential in the production of good dry wine in any climate, and is especially necessary in one which is either cooler or hotter than the normal for the growth of the vine. A variety which gives excellent results in one climate is often quite useless in another. The grapes of Roussillon will not ripen on the Rhine, and those of Burgundy will not bear paying crops in Fresno. The Cabernet Sauvignon, the grape from which the bulk of the Château wines of the Médoc is made, the highest-priced red wines made anywhere, is said to produce an undrinkable wine in Algeria.

For this reason nothing very certain can be gathered regarding varieties suitable for our hotter regions by noting which are planted in other countries. Luckily, the long and complete series of variety tests which the Agricultural College at Berkeley has made during the last twenty years has solved this question very satisfactorily for most parts of California, especially as to what varieties are most suitable for red wine. A short summary of these results was published in the Report of the College of Agriculture in 1898,* and it is interesting to see how far they correspond with the experience and practice of southern French and more particularly of Algerian growers.

* Partial report of Work of the Agricultural Experiment Station of the University of California. Art., "Memoranda on Wine, Table, and Raisin Grapes," pp. 245–253.

In the south of France very few varieties are planted on a large scale, and the great bulk of the vineyards consists of Aramon. This is the ideal grape for quantity, producing an abundance of thin watery wine with good acidity and, though deficient in alcohol, color, body, and flavor, without any positive defects and capable of improvement by blending with suitable heavy wines such as those from parts of Algeria. During the last few years of heavy production and increasing competition with "sugar wines" and with similar but superior wines from the rich plains of Algeria, the Aramon has been much less profitable, and there is a tendency now to plant grapes yielding a less watery product. The principal of these are the Grand Noir (a kind of Bouschet), the Petit Bouschet, and the Carignane. The last would be planted more but for its susceptibility to fungous diseases. In higher and well-drained land the Alicante Bouschet, which is recognized as the best of the Bouschets, is planted, but on lower and richer soil it is found extremely difficult to defend it from oidium and other fungous parasites. A few Matarò, Mourastel, and Cinsaut are found, but not in large quantities. For white wine the Aramon is used principally, together with the Piquepoule and the Terret.

In Algeria at the present time hardly anything is planted except the Carignane and Alicante Bouschet, which unite there, better than any other varieties, productiveness with fair quality. Their susceptibility to disease is more easily controlled in the drier climate of Algeria, but they still require a certain amount of spraying. Other varieties grown there, to some extent, are Cinsaut, Aramon, Mourastel, and Grenache for red, and Farana for white wine. These, especially the first two, do not give thorough satisfaction, on account of their lack of the color, body, and alcohol which constitute the main value of Algerian wines. In the higher regions, especially in the neighborhood of Miliana, where the best wines of the country are produced, a certain amount of Pinot and Gamai vines are grown; but these are gradually giving way to the Carignane, which produces much more abundantly. Very little seems to have been done in experimenting with varieties other than those of France. The vines of Burgundy and the Médoc have generally failed to give the desired results in either quality or quantity, and the varieties adopted are those among the southern French grapes which suit the conditions best.

In the report of the Agricultural Experiment Station referred to above, the varieties recommended for the production of dry red wine in the hotter parts of the San Joaquin Valley are Alicante Bouschet,* Valdepeñas, St. Macaire, Lagrein, Refosco, Barbera; and for the foot-

* This variety and the Petit Bouschet were distributed over California with exchanged labels, and in this way became interchanged at the Experiment Stations. The remarks in older reports, including the one referred to, regarding "Petit Bouschet," apply therefore to Alicante Bouschet.

hills of the Sierra, Alicante Bouschet, Aramon, and Serine. There seems no occasion at present to modify these recommendations, and it is extremely desirable, if dry red wines are to be made in those regions, that larger quantities of these varieties, especially of the first two, should be planted instead of so much Carignane, Mataro, and Zinfandel, which give much inferior results there, so far as regards quality, without a sufficiently great compensation as regards quantity. For dry white wine, the varieties recommended were Burger, Folle blanche, Aramon, for the valley, and possibly Clairette for the foothills; but it is doubtful if at present it is advisable to plant grapes for dry white wine in those localities. That throughout the valley, dry red wines of quality equal at least to those of the plain of the Metidja in Algeria can be produced there can be little doubt, if a certain proportion of Valdepeñas or any of the other varieties recommended are grown to bring up the color, acid, extract, and aroma of the varieties already planted, and if a system of wine-making is adopted which will utilize the good qualities of the grapes and neutralize the injurious effects of the high temperature of the vintage season.

TIME OF GATHERING THE GRAPES.

The stage of ripeness at which the grapes are gathered has great influence on the character of the fermentation and the quality of the resulting wine. Within certain limits the less mature the grapes, the more acid and the less sugar will they contain, and the easier and more complete will be the fermentation. For this reason the premature gathering of the crop has been suggested and practiced as a means of avoiding difficult fermentations in hot regions. So far as the avoidance of "stuck" wines is concerned the method is usually successful; but there is loss in both quantity and quality, which in many cases more than counterbalances the gain.

With regard to the *quality* of the wine, it is well known that the best wine can be made only from grapes which have reached the stage of maturity which is known as "wine-making ripeness." Before that stage is reached the grapes not only contain substances which give a disagreeable harshness to the wine, but have failed to elaborate those other substances to which the finer flavors and aromas of good wine are due. To a certain extent, this stage of ripeness is independent of the degrees of sugar or acidity present, and can only approximately be determined by means of the mustimeter and acid test, or other analytical means alone. While an Aramon in the south of France may have attained its optimum degree of maturity for wine-making purposes when it contains 16% of sugar, a Mataro in the Sacramento Valley may be still far from ripe enough for the same purposes when it contains 20% of sugar.

We can not, therefore, gather our grapes prematurely without some sacrifice of quality, and it is only in the absence of better means of controlling the fermentation that it can be recommended. This loss of quality can be minimized in many cases, however, while still retaining the advantages. If instead of gathering all the grapes when they are imperfectly mature, we allow the main part of the crop to reach "wine-making ripeness" and then crush them with a suitable proportion of very unripe grapes to enhance the acidity, we improve the fermentation with less detriment to the quality. The ripe grapes contain those substances necessary for the quality of the wine, and the unripe those necessary for a good fermentation. This can be done only when the ripe and the unripe grapes can be obtained at the same time, for it is essential that they should be crushed and fermented together. The two kinds of grapes may be of different varieties, ripening at different epochs, or of the same variety, from early and late locations or localities. One of the best methods of applying this remedy is to use the bunches of second crop on the same vines. When the first crop has reached its optimum degree of ripeness, the second crop of most varieties is just in the right condition to correct the lack of acidity in the first. This practice is largely employed in parts of Algeria, and also in South Africa, with great success. The resulting wines, while showing a slight "greenness" to the palate, are much superior in quality to those made altogether from grapes gathered prematurely, while fermenting with equal ease and completeness.

With regard to the *loss in quantity* some interesting conclusions may be drawn from some recent French investigations.* These show an average increase of volume in grapes of 2% per day during the two or three weeks preceding maturity, and an increase of .7% per day of the sugar during the same period. The actual figures noted vary within very wide limits with different varieties of grapes and different localities, but the average of all the results will doubtless give us an approximation to the average in practice. If, then, we gather the grapes before they attain the proper degree of maturity, we obtain a smaller quantity of wine of a lower degree of alcohol. This loss may be considered as the cost of the acid in the partially ripe grapes, to which the better fermentation is due. If we compare this cost with that of a sufficient amount of tartaric or citric acid to attain the same result, we will find it much higher. An example will make this clearer. If we have a vineyard where the grapes at maturity contain 22% of sugar and .4% of acidity, we might, by picking them a week before maturity, have sufficient acidity to insure a thorough fermentation. At this time (using the figures given above) the grapes would contain about 16.9% of sugar and .6% of acidity, and

*Aimé Girard et L. Lindet: "Recherches sur le développement progressif de la grappe de raisin." Paris, 1898.

the quantity of bunches that at maturity would weigh 2,000 pounds would at this time weigh only 1,780 pounds. The cost, then, of the extra .2% of acidity that we would obtain may be reckoned as follows:

220 pounds of grapes, at $15	$1 65
90 pounds of sugar, at 3 cents	2 70
Total cost of acidity per ton of grapes	$4 35

Reckoning the price of tartaric acid at 25 cents per pound, the cost of this .2% of acidity would be only $1; and if citric acid were used, the practically equivalent amount would cost even less. These figures are merely approximate, and the difference in cost may often be less than this; but it is just as likely to be more.

If, then, we consider the *losses in both quality and quantity*, it is rarely if ever advisable to pick grapes prematurely for the purpose of promoting a good fermentation; cheaper and better methods are usually available. The principal exception is when a second crop is available in the right condition when the first crop is being picked, especially when this second crop is of a variety which can not be depended on in the locality to attain full ripeness later.

Another point of practical importance regarding the time of gathering is worthy of notice. In large vineyards of one variety of grape or of several ripening at about the same time, it is impossible to gather all the grapes just at the most desirable stage of maturity. For this reason it is usually necessary to commence gathering before the grapes have quite reached this stage, and to continue after they have passed it. In Algeria it is usual to commence the vintage as soon as the grapes are capable of producing wine of 8% of alcohol, and before the vintage is over they are usually sweet enough to produce wine of 12% to 14% of alcohol. If all the fermentations are complete a good average wine is made by blending all together. The high acidity of the early-gathered grapes supplements the low acidity of the late-gathered grapes. Too much acidity in the must is a much less serious defect than too little, as much is deposited during fermentation, and more during the first few weeks following. The cause of this is the presence of alcohol and the fall of temperature, both of which conditions make the wine less capable of holding the acid tartrates in solution. For this reason, when the wine made toward the end of the season is deficient in acid it is desirable to blend it with the early-made acid wine as soon as possible, before the latter has deposited too much of its acidity. Some wine-makers in fact mix the early-fermented wine with the over-ripe grapes when they are crushed or when they have half fermented. This utilizes the surplus acidity most effectually, and at the same time aids fermentation by diluting the sugar and cooling the temperature of the later fermentations. The method has the defect, however, of entailing a double handling of a part of the wine, and exposing a wine which is already

made and sound to the risks of a second fermentation under less favorable conditions than the first.

METHODS OF CULTIVATION.

The composition of the grapes, as well as the amount of the crop, can be modified very considerably by the system of pruning, tillage, irrigation, and manuring adopted. The old idea that the smaller the crop the higher the quality of the wine is by no means always or even generally true. Anything which weakens the vine beyond a certain limit will decrease its bearing capacity, and at the same time injure the quality of the grapes. Vines weakened by disease, soil exhaustion, or lack of soil moisture produce badly ripened grapes, deficient in sugar, acid, and other elements which are necessary for the production of good wine. This is especially true of any condition which prevents an abundant growth of healthy leaves throughout the season. When the leaves cease to perform their functions properly, the grapes cease to develop. For this reason it is often possible, by appropriate cultural methods, to increase the quantity of the crop, and at the same time to ameliorate its quality. Anything which increases the size of the bunches and berries without interfering with their normal ripening usually improves their quality. This is particularly true in hot climates, where there is ordinarily no lack of sugar in the grapes or where there is often too much.

On the other hand, anything which increases the number of bunches at the expense of the proper development of the individual berries usually produces a deterioration in the quality; and often the increase in quantity is more apparent than real, as small, badly developed grapes yield comparatively little wine.

Pruning.—The larger and more vigorous a vine, the more grapes it is capable of bringing to perfection. The more buds one leaves on a vine in pruning, the more bunches it is enabled to produce. Our pruning should be so calculated, therefore, as to give the vine the opportunity to produce as many bunches as it can properly support and bring to the desired degree of maturity. A vine pruned too long or given too many spurs may yield a large number of bunches, but the grapes will be deficient in juice, sugar, acid, and all the constituents essential for good wine. Increasing the amount of bearing wood on a vine will increase the crop only within certain limits. To pass these limits we must strengthen the vine by improved tillage, irrigation, and fertilization. An essential condition of both good crops and good wine is a strong healthy vine.

Irrigation.—It was long believed that it was impossible to make good wine from irrigated vineyards. But this is no more true than the

equally widespread belief that irrigation is incompatible with the production of other good fruit. Irrigation properly applied is in fact one of the surest means of insuring both the quantity and quality of the crop, as it gives the vine the amount of water it needs at the time it needs it. It frequently occurs during the latter part of dry seasons, especially with late ripening varieties such as Matarò, that the grapes suddenly cease to develop either in size or sugar, in spite of the warm weather. This is because the vegetation of the vine is arrested and the leaves and roots fail to perform their functions properly. Grapes grown on a dry hillside may, under such conditions, fail to develop more than 16% of sugar, while the same variety in a moister soil with the same weather conditions may reach 20%. Under such conditions irrigation, when practicable, will remedy the trouble. Irrigation may also be used to remedy the opposite condition, viz.: the development of too much sugar in the grapes. Many convincing tests of summer irrigation of vines have lately been made in southern France. Those of A. Müntz* are particularly suggestive to Californians, as they were made in the Roussillon, where the climate resembles more nearly that of California than in any other part of France. In a series of twelve tests made with Aramon and Carignane vines, late summer irrigation increased the weight of grapes produced 29%, and the weight of sugar per acre 20%. The average composition of the grapes from irrigated and from non-irrigated vines was as follows:

	Sugar.	Acid.
Irrigated	18.8%	1.11%
Non-irrigated	19.6%	.96%

The wine made from the irrigated grapes contained 11% of alcohol, and that from the others 11.5%, but otherwise the quality was identical. Calculating the value of the crop of wine at 2 francs per degree per hectoliter—the market price at the time of the test, corresponding to 17½ cents per gallon for wine of 11% alcohol—the gain per acre due to the irrigation was $20. There can be no doubt that in many cases the gain in California from irrigation properly applied would be proportionately greater where the grapes tend to produce too much sugar and too little acid for proper fermentation. In many vineyards in the irrigated portions of California undoubtedly as much water as the vines can profitably use is applied, and in some cases more; but no fear need be entertained that irrigation will depreciate the quality of the wine if it does not decrease the sugar-contents of the grapes below 19% (about 20.2%, Balling). There is far more danger that insufficient irrigation

* "De l'effect des Arrosages Tardifs." A. Müntz, in "Revue de Viticulture," vol. 11, p. 541.

* M. G. Brémond more than doubled his crop by judicious irrigation, at the same time improving the quality and alcoholicity of his wine. "Progrès Agricole et Viticole," vol. 32, p. 697.

in the hot interior valleys will result in grapes deficient in acid and with excessive sugar, giving unsound and inferior wines.

The *time of irrigation* is of equal importance with the amount. It is very important that the vine should have sufficient moisture available during the period between what the French grape-growers call the "Véraison"—(the time when the grapes, having attained almost their full size, commence to color)—and full ripeness. During this period there is a migration toward the fruit of materials accumulated in various parts of the vine, and great changes take place in the composition of the grapes. Growth relaxes in the leaves and shoots, which become paler. It is a critical period in the maturing of the crop, and if the vine is not well nourished and supplied with water it is not able to supply the energy necessary for the profound chemical and physical changes taking place in the fruit.* During the latter part of this period, which lasts for from *four* to *six* weeks, it is very important that the vine should not receive a check from lack of available moisture. It is often observed in France and Algeria that when the autumn is hot and dry, the development of the grapes is arrested and the crop is deficient not only in quantity but often in sugar and acid. This explains the good effects of late irrigation, which Müntz in Roussillon (already quoted) and others in southern France have found so noticeable.

Fertilization.—With regard to the effect of fertilization on the quality of the grapes, the same line of reasoning applies as with irrigation. A starved vine will produce not only few grapes but inferior grapes, and a fertilizer which will increase the crop will usually improve its quality; and no deterioration of quality from this source need be feared so long as the sugar-content of the grapes remains sufficiently high. Fertilization of the vines is carried out very thoroughly and regularly in southern France, and the best practice is considered to be an annual treatment. The crop is very much increased by this means, often doubled without sacrifice of quality.†

MORE COMPLETE UTILIZATION OF THE SUBSTANCES IN THE GRAPES.

Some of the defects of the wines of hot countries may be attributed, not so much to deficiencies in the grapes, as to the failure to properly utilize the materials present. The fermentation of red grapes with the stems has been advocated as a means of increasing the body, acidity, and tannin-contents of the wine. In the south of France this is the common practice. The observed good effect is due, however, not to the materials in the stems, but to those in the skins, which the presence of the stems permits to be more thoroughly extracted. The good effects of fermenting with the stems, then, are mainly indirect, and may be

* G. Foix: "Cours Complet de Viticulture," p. 267.

† Degrully: "Progrès Agricole et Viticole," vol. 32, p. 669.

obtained by any means which promotes the extraction of matters from the skins, such as stirring, long maceration, etc. On the other hand, the direct effect of the stems is to give a harshness to the wine which is incompatible with the best quality, and the practice is advisable, therefore, only where very common wines are made. In Algeria the stems are usually rejected, and the extraction of color and tannin from the skins is promoted by pumping-over during the last stages of fermentation.

In Algeria the use of cooling machines to moderate the heat of fermentation, while almost completely successful in its object of enabling the cellarman to be sure of producing a sound dry wine, has brought a very serious trouble in its train. The main value of Algerian wines, the special character which made them desirable to the wine merchants of France, was their heavy body, high astringency, and deep color. These three important qualities have all been modified by the cool fermentations now practiced. Wines which are not allowed to exceed 90° or 93° F. during fermentation, though they are usually sound and dry, and free from those defects and diseases which used to characterize so many Algerian wines, possess much less body, color, and tannin than the wines made by the old method. The gain, therefore, of greater certainty in results and less spoiled wine is to a great extent offset by the loss of much of the character which constituted the value of the old wines when they were successfully made. It is beginning to be realized now that too much emphasis has been placed on the ill effects of high temperature in fermenting red wine, and the good effects of those temperatures lost sight of. Attempts have therefore been made lately to devise a system of wine-making which will combine the good effects of high temperatures in the complete extraction of the grapes, and the good effects of low temperatures in the complete fermentation of the wine and the absence of injurious ferments.

The most notable system of this kind, and the only one in practical use in Algeria, is that of M. Debono, a large wine-maker of Boufarik. The results of the method were kindly shown at the cellar of M. Duroux at Rouiba, where 200,000 gallons of wine were made by this method last year. The wine, as seen in December, 1904, two months after the vintage, was clear, dry and sound, and superior in color, body, and taste to that of any other large cellar tasted in Algeria. The method in brief is as follows:

1. The grapes are crushed and stemmed into amphoras* of 11,000 gallons capacity, with strainers at the bottom.

2. The must is then drawn off. This is done preferably immediately after crushing, but in practice often after fermentation is half over.

*The amphoras used in Algeria for fermenting and storing wine are vats shaped like huge bottles, and constructed of concrete, masonry or brick, and lined with glass.

3. This must is pumped into amphoras of 12,500 gallons capacity, treated with sulfite to moderate the temperature, and allowed to ferment until all but about 2% of the sugar has disappeared.

4. As soon as the must contains only 2% of sugar it is pumped back on to the pomace in the original amphora.

5. The pomace in this amphora has meanwhile become very hot—44°–45° C. (111°–113° F.).

6. The must is now pumped over the hot pomace repeatedly until it has extracted sufficient color and tannin, and is then pumped back into the 12,500-gallon amphoras, where fermentation is completed. Usually the wine is quite dry by the time it arrives in the larger amphoras the second time.

The time of the operation from the crushing of the grapes until the wine is placed in the final amphoras is usually about four days. The method requires constant vigilance day and night.

The must should not be allowed to become quite dry before being pumped over the pomace, or the wine will be inferior in color and quality. On the other hand, it must not be pumped over with more than 4% of sugar, or there is danger of a hot fermentation and its accompanying effects.

By this method we get the good effects of hot temperature in the pomace vat, where it macerates the skins and so enables the must to extract the color, body, and tannin. At the same time we get the good effects of low temperature in the must vats, where the wine becomes dry and acquires the bouquet characteristic of cool fermentations. The reason we do not get the bacterial fermentations usually accompanying hot fermentations is probably because the great bulk of the wine never becomes hot, and the yeast remains strong and healthy and thoroughly defecates the wine before the bacteria have an opportunity to injure it. In an ordinary hot fermentation the weakening of the yeast has probably more to do with the growth of bacteria than the favorable influence of the high temperature. There is undoubtedly some loss of alcohol in the pomace vats, due to the very high temperature, but this is apparently more than offset by the gain in alcohol in the cool must vats. I was assured that the wines fermented in this way usually showed a higher degree of alcohol than those fermented in the ordinary way.

Effects of High Temperatures.—The effects of various degrees of temperature in the process of wine-making are of two kinds, which should be carefully distinguished. They are: (1) Those which are due directly to the degree of temperature and its immediate action on the must or wine; and (2) those which are due indirectly to the degree of temperature through its modifying influence on the character and kind of the micro-organisms present. It is, to a great extent, to a failure to prop-

erly recognize this distinction that so much difference of opinion exists as to the most favorable temperature for fermentation, and as to the advisability of pasteurizing must or wine.

Under the ordinary conditions of wine-making; the second of these groups of effects is by far the more important. That is, the great differences found in wines fermented at different temperatures between the extremes of 20° C. (68° F.) and 40° C. (104° F.) are due principally to the differences caused in the kinds and proportions of the various molds, yeasts, and bacteria present, and to the different physiological activities of these micro-organisms at various temperatures. The *direct* effects of much wider ranges of temperatures than these, if not continued too long, are in fact extremely slight, proportionally, in the case of must and, when evaporation is prevented, of wine. Clear grape-must may be subjected to any temperature between 0° C. and 80° C. (176° F.) for a short time without any very appreciable effect on its appearance, flavor, or chemical composition. The same is true of wine, if at the higher temperatures the heating is done in such a way as not to cause evaporation of the alcohol.

Practically all the ill effects of a hot fermentation, *i. e.*, production of volatile acids and mannite, failure to convert all the sugar into alcohol, disagreeable flavors, persistent cloudiness, etc., are due, not to the heat itself, but to the bacteria, which multiply and flourish at high temperatures, and to the weakened yeast, which at these temperatures becomes abnormal and acts upon the must in a way very different from its normal and healthy action. If, then, we heat a must to 40° C. (104° F.) artificially when there are no bacteria or yeasts present, none of these undesirable results follow. The taste common in wine fermented at high temperature, often described as a cooked taste, is not, therefore, due to the heat directly, but to the action of bacteria, or perhaps to the action of abnormal yeast.* A real cooked taste, that is, the taste of caramelized sugar, may be given to must by heating it too high, and this is in fact done in some processes of wine-making where the must, or part of it, is concentrated by heating in boilers. It has been shown experimentally, however, that must may be heated to 80° C.† (176° F.) or even 90° C. (194° F.) without contracting this cooked taste in the slightest degree. Where this taste is acquired at an apparently lower temperature, it is due to the fact that, owing to the method of heating over a fire or by means of superheated steam pipes, some of the must is heated much higher than 90° C. and imparts a taste to the whole.

Another taste, undesirable in dry wines, often associated ‡ with high temperatures, is that of "rancio." This is the taste acquired by wines upon exposure for a long time to the air. The taste is desirable in

* This is well shown in the experiments described on page 25.

† See U. C. Bull. 130, page 6.

‡ Barba, in "Annales de la Société des Viticulteurs de France," vol. VI, p. 96.

ports, sherries, and other sweet and liqueur wines, and many processes are used to facilitate and hasten its acquirement. All these processes aim at increasing the oxidation of the wine, either by fuller exposure to the air or by exposure at higher temperatures. This taste was at one time accredited to the action of a fermentative organism, but it is now well known to be due to simple direct oxidation. Must or wine sterilized and kept in sterilized vessels in contact with the air acquires the taste quite as quickly as when unsterilized. The factors which determine the amount of the taste and the rapidity with which it is acquired, are the temperature and the exposure to the air. If we wish to prevent the acquisition of "rancio," therefore, we must avoid undue aëration and high temperatures. That exposure to high temperatures alone continued for a short time will not cause a wine to become "rancio" is proved by the pasteurization of dry wines at 160° F. out of contact with the air. It has also been proved that must may be exposed to the same temperature under the same conditions with equal impunity. Moreover, Professor Barba, of the Œnological Station at Nimes, has shown that must and grapes can be heated to 70° C. (176° F.) in an open vat for a short time without becoming "rancio." At the Experiment Cellar of the Agricultural Department of the University of California it has been shown that grapes can be heated gradually up to 48° C. (118½° F.) for six hours without any special precautions to exclude the air, and acquire no taste of caramel or rancio. In fact, wines made from grapes heated in this way were remarkable for their clean taste, freshness, and bouquet—qualities associated with cool fermentations.

The following table summarizes the main effects of high temperature in the making of dry wine:

A. Direct effects:—
- (*a*) Beneficial:
  1. Increase of color.
  2. Increase of tannin.
  3. Increase of body.
- (*b*) Injurious:
  1. Oxidation.
  2. Caramelization.
  3. Loss of alcohol.
  4. Loss of bouquet and freshness.

B. Indirect effects:—
- (*a*) Beneficial:
  1. Destruction of injurious ferments (sterilization) in the unfermented must (artificial heating).
- (*b*) Injurious:
  1. Growth of injurious ferments in the fermenting must (hot fermentation).
  2. Abnormal excretions of the yeast.

In order to utilize our raw material to the utmost it is necessary to devise a system of wine-making which will combine the beneficial effects of heat in the extraction of color, tannin, and body with those of cool

fermentation in producing bouquet, freshness, and maximum amount of alcohol. This is what is done to a certain imperfect extent by the Debono method. If the spontaneous heating of the pomace which occurs in that method could be replaced by an artificial heating, the method would be more nearly perfect and more under control. The experiments of Rosenstiehl, Kühn, Mathieu, and others in sterilization of musts for the purpose of using pure and selected yeasts have shown that this can be done. Their methods, however, are rendered unnecessarily troublesome and expensive by attempting to effect: (1) complete sterilization, and (2) complete absence of air. The researches of Kayser and Barba show that neither of these objects are necessary for the ordinary purposes of wine-making, and their results have been fully corroborated by tests made at the California Experiment Station at Berkeley.

Extraction of Color and Tannin by Heat.—In 1898 a series of experiments was made at Berkeley to determine to what extent color and tannin could be extracted before fermentation by direct heating of the grapes. A summary of the results is shown in the following table:

TABLE I. *Extraction of Color and Tannin from Fresh Grapes by Heat.*

		Color.		Tannin.	Acid.
		Tint.	Intensity.		
1. Witness. (Ordinary fermentation at 30° C.)		2 VR	66.6	.357	.45
2. Heated to 50° C. in one hour	1.00 hour	5 VR	19.3	.108	.38
(*a*) Kept at 50° C. for 30 minutes longer	1.50 "	3 VR	37.7	.135	.37
(*b*) Kept at 50° C. for 90 minutes longer	2.50 "	2 VR	74.0	.217	.30
3. Heated to 60° C. in 80 minutes	1.30 "	VR	95.0	.328	.50
(*a*) Kept at 60° for 60 minutes longer	2.30 "	*VR+	133.0	.385	.45
(*b*) Kept at 60° C. for 120 minutes longer	3.30 "	VR+	174.0	.500	.52
4. Heated to 70° C. in 90 minutes	1.50 "	VR+	138.0	.246	.48
(*a*) Kept at 70° C. for 45 minutes longer	2.25 "	VR+	160.0	.369	.46
(*b*) Kept at 70° C. for 90 minutes longer	3.00 "	VR+	160.0	.450	.46
5. Heated to 65° C. in 3 hours and 20 minutes, after adding 10.5% alcohol†		VR	120.0	.552	.38

*The + indicates the color brighter than the first tint of the colorimeter.
†Corrected for dilution and contraction due to the addition of alcohol.

With regard to the extraction of color, an inspection of the intensity shows that heating the grapes for two hours and a half at 50° C. (122° F.) extracted more color than an ordinary fermentation at 30° C. (86° F.), while heating them for about the same time at 60° C. (140° F.) or one hour and a half at 70° C. (158° F.) extracted about twice as much. Still longer heating extracted still more color, the maximum being about three times that of the ordinary fermentation. It may be noted at the same time that the kind of color or tint was in all cases better than that of the fermented wine, except where the heating had been insuf-

ficient. Heating for one hour and a half at 50° C. was insufficient to properly extract the color, either as regards tint or intensity. In all the other cases the color was not only better than that of the fermented wine, but extended beyond the limits of the scale toward the VR end, showing that it was better than that of any wines ordinarily found in France where the scale is adopted.

It has been objected that the color extracted by heat in this manner is of a different nature from that extracted by fermentation, and that most of it would be deposited by the alcohol formed during fermentation. The fifth experiment, at the bottom of the column, shows that, while this may be partly true, yet with the addition of 10½% of alcohol before the heating, twice as much color was extracted in 3⅓ hours at 65° C. (149° F.) as by fermentation, and that the tint was better.

In order to test whether this destruction or precipitation of color by the alcohol continued on further contact, the tests summarized in the following table were made.

A quantity of Lagrein grapes from Tulare was crushed and heated to 70° C. to extract the color. The must contained 27.4% of solid contents by spindle and .47% of acid calculated as tartaric. The color of the must at the commencement of the experiment (September 23, 1899) was VR 85.3. The colored must was placed in ten bottles holding 125 c.c. each, and various amounts of alcohol added to each. Two series were made, to one of which was added .4% of tartaric acid. The bottles were filled quite full, well corked, and sterilized at 60° C., in order to eliminate as much as possible the influence of oxygen and fermentative organisms.

TABLE II. *Effect of various amounts of Alcohol and Tartaric Acid on the Stability of the Coloring Matter of Red Grapes. Color after 6½ Months.*

	No Acid Added.		Acid Added.	
	Tint.	Intensity.*	Tint.	Intensity.*
1. Must + 0% of alcohol	2 VR	57.9	3 VR	58.8
2. Must + 5% of alcohol	2 VR	53.2	3 VR	56.9
3. Must + 10% of alcohol	3 VR	39.6	3 VR	57.7
4. Must + 15% of alcohol	3 VR	41.1	3 VR	55.8
5. Must + 20% of alcohol	4 VR	41.2	4 VR	56.6

*These figures are corrected for the dilution and contraction due to the addition of alcohol.

No. 1 shows that the must to which no alcohol was added lost 32% of its color in six months, and that this loss was not prevented by the addition of a considerable quantity of tartaric acid. The must to which was added 5% of alcohol lost 38% of its color, and that with 10% of alcohol 46%. The addition of 15% and 20% of alcohol had no more effect in destroying coloring matter than 10%, though there was a slight degradation of tint. The last column shows that the addition of tar-

taric acid was very effective in counteracting the effect of the alcohol, as the loss of color due to alcohol where tartaric acid was added averaged only 34%, or very little more than that of the pure must.

That heating the grapes is equally effective in extracting the tannin is well shown by Table I. The tests indicate that, with the grapes used, sufficient tannin is extracted before the maximum color extraction is reached. They also indicate that there is danger that too long or too high heating may extract too much tannin, and that it may be impossible to get the maximum color extraction without getting too much tannin. However, test 4*a* shows that twice the color may be obtained by heating to 70° C. (158° F.) for an hour and a half before the tannin-content reaches that of an ordinary fermentation. With further heating more tannin may be obtained, and the maximum was not reached in any of the tests. Undoubtedly, prolonged heating would dissolve some of the tannin in the seeds, so that the astringency could probably be increased as much as desired, even with grapes normally lacking in tannin. The presence of too much tannin is much less dangerous than too little, as it increases the keeping qualities of the wine and disappears gradually with age or can be removed to a great extent by fining. Moreover, Professor Barba has shown that the tannin in the must is very rapidly eliminated if the must is kept without fermentation.* If, therefore, it is necessary to heat the grapes for a long time to extract the color, the superfluous tannin can be diminished to any desired extent by delaying the fermentation.

These laboratory experiments demonstrated the probability that color and tannin could be extracted by heat, the red must separated from the pomace and fermented in the same manner as white wine. If this could be done without deterioration of quality from some unforeseen cause, a great advance would have been made in the certainty of making good wine in hot localities. The cool fermentation of must without the pomace is a comparatively simple operation.

While these laboratory tests were in progress, corresponding wine-making tests were undertaken in the cellar to throw light on the feasibility of the method in actual practice.

About three quarters of a ton of red grapes was obtained from the Tulare Experiment Station. These grapes were grown in black, alkaline, sandy soil in one of the hottest regions of the State, where all the conditions which are supposed to render a hot region unsuitable for the production of dry wine are at their worst. The grapes consisted of Lagrein 75%, Malbec 14%, and Valdepeñas 11%, and the mixture contained 24.64% of fermentable sugar and .34% of acid calculated as tar-

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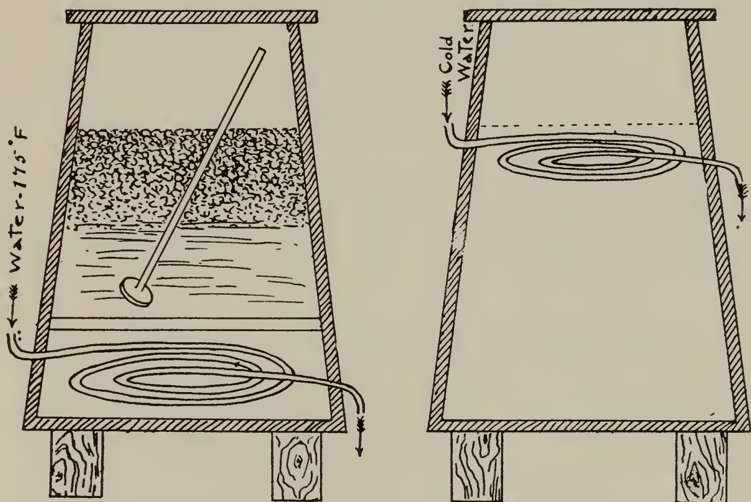
* Barba, M., in "Annales de la Société des Viticulteurs de France," vol. VI, p. 100:

Tannin in must of heated grapes immediately after heating	.910
Tannin in wine of heated grapes fermented immediately after heating	.820
Tannin in must of heated grapes one day after heating	.720
Tannin in must of heated grapes four days after heating	.260

taric. The grapes were therefore totally unfitted for the production of dry red wine by the ordinary methods of wine-making. Grapes with such high sugar-content and low acidity would fail to ferment dry, not only in the San Joaquin Valley but in any part of California, and, in nine cases out of ten, the tanks would almost certainly "stick" in fermentation, and the wine spoil before it was three months old. No grapes more suitable to detect any weak point in the method could have been chosen.

One-fifth of the crushed and mixed grapes was fermented in the ordinary way in an open fermenting vat. More than the usual care was taken, the grapes being thoroughly stirred twice a day and the vat kept covered. The fermentation was cool, never exceeding 79° F., and the wine was nearly dry at the end of thirteen days.



Heating Vat. *Cooling Vat.*

FIG. 1. Heating and Cooling Vats. Showing the plan adopted for heating the grapes and cooling the must before fermentation.

The other four-fifths of the crushed grapes was placed in a small fermenting-vat, which they about two-thirds filled. At the bottom of this vat was a coil of half-inch block-tin tubing, through which a stream of water of a temperature of 80° C. (176° F.) was run. The vat was then covered with a canvas sheet, which was removed every half hour and the heating grapes thoroughly stirred. The heating commenced at 10 A. M., the temperature of the grapes being 18.5° C. (65° F.), and continued until 4 P. M., when the temperature of the grapes had risen gradually to 48° C. (118° F.). The red must was then drawn off and mixed with the must pressed from the heated pomace, and placed in an open vat (see Fig. 1).

The color of the must, as it ran from the heater, was 1 VR—78, and of that which ran from the press VR—102. The amount of tannin

in the mixture was .262%. The must was cooled, immediately after mixing, to 30° C. (86° F.) by means of a coil similar to the heating coil, through which water at 20° C. (68° F.) was run. It was then divided into four equal lots, numbered 2717*a*, 2717*b*, 2717*c*, and 2717*d*, each of which was placed in a separate keg. Nos. 2717*b* and 2717*d* each received an addition of tartaric acid. Fermentation was started by the addition of yeast and was finished in all cases in twelve days, the temperature being practically the same as that of the ordinary fermentation, never exceeding 26° C. (79° F.). As soon as the wines were dry they were racked into clean casks, kept for a few days in the fermenting-room at 21° C. (70° F.), and as soon as clear racked again and put in the cool storage cellar. The wine fermented in the ordinary way received the same treatment after fermentation. Some of the data obtained are shown in the following table:

	Must.	Wine.					
	Acid.	Acid.	Tannin.	Alcohol.	Solid Contents.	Time of Fermentation.	Color.
Witness: 2717	.34	.38	-------	-------	-------	13 days	3 VR 30.7
Heated grapes. 2717*a*	.54	.41	.151	14.25	3.15	12 days	2 VR 29.2
Heated grapes. 2717*b*	.60	.60	.153	14.10	2.81	12 days	2 VR 35.7
Heated grapes. 2717*c*	.44	.47	.153	13.90	3.15	12 days	2 VR 25.0
Heated grapes. 2717*d*	.53	.53	.139	14.10	2.60	12 days	2 VR 32.0

The four wines made from the heated grapes were bottled when they were eighteen months old, and were in excellent condition. They remained in the cellar four years, when they were opened and tasted. They were all perfectly sound and clear. A thin, tightly adhering deposit had been formed in the bottles, proving by its character the perfect keeping-qualities of the wine. The wines were fresh, clean tasting, and of good color. The bouquet was remarkably strong, proving conclusively that heating the grapes to 48° C. does not diminish this quality in the wine, and even tending to show that, on the contrary, it increases it.

This series of tests has clearly demonstrated a fact of great importance to wine-makers of the interior valleys, viz: that grapes grown in rich, sub-irrigated soil in the hottest part of the valley can, if properly handled, be used for the production of not only a sound dry red wine, but of a wine of exceptional quality, superior in every respect to the *bulk* of the wines produced in any part of California or of Europe. Whether fine wines, equal to the best of the Médoc and Burgundy or of the coast valleys of California, can be produced there is a matter of much less importance at present, and can be left for the future to decide.

ADDITION OF SUBSTANCES DEFICIENT IN THE GRAPES.

Water.—One of the most frequent causes of difficult fermentation and spoiled wine, when the attempt is made to make dry wine in a hot climate, is extreme sweetness of the grapes. Under the most favorable conditions it is impossible to cause the transformation into alcohol of more than about 28% of sugar in the must, and this only after a very long time. Under ordinarily favorable conditions it is impracticable to ferment out more than 25%, producing 14.5% of alcohol. Under the conditions existing in an ordinary cellar in a warm locality the limit is much lower, and may be taken as somewhere about 22% of actual fermentable sugar, corresponding to between 22.5% and 23% on Balling's saccharometer, and capable of yielding a wine containing 13% of alcohol. Even with this amount of sugar, most of the fermenting vats will "stick" with 2% to 4% of unfermented sugar in warm seasons with ordinary methods of wine-making. Grapes containing only 19% of fermentable sugar can, however, be nearly always fermented dry with the ordinary methods, except in very hot seasons or where very large fermenting-vats are employed.

As about three quarters of the weight of ripe grapes consists of water, the addition of a little more when there is too much sugar naturally suggests itself. The procedure has been and is still frequently used, but often with but indifferent success. The reasons for failure are two: Firstly, the dilution of the sugar entails at the same time the dilution of the other constituents of the must, notably the acid; and secondly, impure water is often used, water containing large amounts of salts or of organic matter, which materially alters the flavor of the wine and the character of the fermentation. The dilution of the acid is the most serious defect, and is the more serious the riper the grapes, for the more sugar there is present usually the less there is of acid. For example: if we dilute a must containing 24 grams of sugar in 100 c.c. (about 24.4%, Balling) and .4% of acid to 22½ (23.2%, Balling), by adding 7% of water we also reduce the acid, which is already too low, to .37%. Wherever dilution is practiced, therefore, it is almost always necessary to supplement the acidity. Moreover, the practice can be used successfully only where the grapes are naturally high in extract and coloring matter. In other cases the wine will be thin and flat. There is a well-founded prejudice against adding water to wine either before fermentation or after. This has its origin, to a great extent, in the fact that in Europe the addition of water is done for purposes of fraud, with the simple object of making more gallons of wine out of a given quantity of grapes. The addition of water to the wine after the fermentation is never admissible under any circumstances, as it can never improve the quality in any way, and will, in fact, always injure it. There are, however, cases where it is possible, by a limited amount of dilution before

fermentation, to produce a good, sound, dry wine, where it would be very difficult to do so without. This applies particularly to California, where the richness of the grapes in all constituents except acid is often so great that even after the addition of a certain amount of water to the must the resulting wine has a higher degree of alcohol and extract than the bulk of European wines, and could not be recognized as watered by any "alcohol and acid" or other chemical or organoleptic test. However, the practice is to be commended only under exceptional circumstances, as there are almost always better ways of attaining the object—a thorough, clean fermentation.

Tartaric Acid.—This acid is found in larger or smaller amounts in all grapes and in all wines. Some of the acid exists "free" (that is, uncombined with any base), but most of it occurs in combination with potash and lime. The principal acidity of most grapes and wines is due to the acid salt of potash and tartaric acid, bitartrate of potash, more commonly known as cream of tartar. Malic acid and its salts also occur in considerable amounts, and some other acids in very small amounts. Thus the acidity of a must is due to a number of acids and acid salts, which vary somewhat in their proportions as well as in their total amounts in various grapes and at various stages of ripeness. In unripe grapes the free acids predominate; in ripe, the acid salts.

The importance of the acidity of the grapes in wine-making is so great that no wine-maker should be without the means of determining its amount. It is not necessary to know the exact amount of each constituent of the acidity, and to determine it would be difficult and impracticable in wine-making; but some measure of the "total acidity," which will give us an idea of its effect on the fermentation and on the quality of the wine, is both useful and necessary. This may be found in various ways, but the results are always given as sulfuric or tartaric acid. That is, when we say a must has .8% acid as tartaric, we mean that its acidity has the same effect on the reagents used in determining it as .8% of pure tartaric acid would have. This does not give us the exact amount of tartaric or of any of the acids in the must, but as the various acid constituents occur in about the same relative proportions in all grapes that are not very unripe, it gives us a convenient way of comparing different grapes and of judging whether their acidity is sufficient for our purpose.

The acidity affects the quality of the wine both directly and by its effect on the fermentation. A dry wine requires a certain amount of acidity or it will taste flat—a red wine with insufficient acidity drops its color very rapidly. Its most marked effect, however, is due to its influence on the fermentative organisms in the must. Yeast will multiply and grow in presence of a larger amount of acid than any of the ordinary disease germs and bacteria occurring in must and wine. For

this reason a very acid must nearly always undergoes a clean and thorough fermentation, and the resulting wine clears rapidly and keeps well.

It is impossible to say what the most desirable degree of acidity is, as this varies with so many conditions. Red wine requires more than white, as the former loses much in fermenting. Coloring grapes, such as the Bouschets, require more than ordinary red grapes, as the coloring matter is less stable. American grapes, such as Lenoir, require still more, as they are liable to a peculiar change when lacking in acid, which destroys their color. Moldy, unripe or otherwise defective grapes require more than good grapes, on account of the large numbers of bacteria and molds they contain.

According to Bouffard,* the average acidity of good red wines in the south of France is .6% to .9%. Good wines may have less than this, but they are then difficult to handle. As some of the acidity is lost in fermentation, the must should have more than this. Roos † gives as the most favorable acidity for red wine grapes in the south of France, the following:

For Aramon, Carignane, and most red grapes	0.8%
For Bouschets	1.0%
For Jacquez (Lenoir)	1.2%

The acidity of ripe California grapes very rarely reaches these figures, especially in the hotter parts, and this lack greatly intensifies the unfavorable effect of hot fermentation. Even in the south of France the grapes very commonly fall below these figures when allowed to mature completely. There, the difficulty is usually overcome by gathering the grapes under-ripe, to the detriment, as already observed, of both quality and quantity. In large vineyards, however, it is often impossible to gather all the grapes before they are thoroughly ripe, so the augmentation of the acidity by addition of acid to the grapes or wine is becoming a common practice both there and in Algeria. The addition of the acid to the wine after fermentation is practiced only when its object is to increase the acidity for the taste of certain French markets, or to increase the stability of the coloring matter in wine from color-grapes. Jacquez wine is sometimes dosed with tartaric acid to the extent of 2%, which makes it quite undrinkable but useful to blend with wines lacking in both acid and color. Tartaric acid added to the wine after fermentation gives a harshness to the wine which is absent when the acid is added to the must before fermentation. The only object of adding it after instead of before is that a certain proportion is precipitated, and this in the latter case is lost in the pomace or thick lees, while in the former it is recovered in the argol deposited in the casks.

* "Revue de Viticulture," vol. 10, p. 545.

† Roos: "L'Industrie Vinicole Meridionale." Montpellier, 1898.

For the purpose of regulating the fermentation, however, it must be added to the crushed grapes, and in this case, unless used in extravagant quantities, it has absolutely no ill effects on the flavor of the wine. How much it is necessary or safe to use can be determined only by experiment in each vineyard with each variety of grape. In a general way, it may be said that experience has shown that with grapes very low in acidity it is neither safe nor necessary to add enough acid to bring up the amount to the figures given by Roos as normal. For example, if a must shows .4% of acidity it is usually sufficient to add enough tartaric acid to bring this acidity up to .6%, that is 4 pounds to the ton of grapes. Some writers say it is rarely desirable to exceed 2 pounds to the ton,* while others believe it is quite admissible to go as high as 5, 6, or even 8 pounds per ton.† In general, the best modern practice seems to be not to exceed 4 pounds per ton,‡ and this in all cases is sufficient to insure a good fermentation so far as acidity alone can do this. The reason of this is that the addition of a certain amount of tartaric acid to the must has a much stronger effect on regulating the fermentation than an equivalent amount of natural acidity, because it increases the "free" acid and diminishes the "combined acid" or cream of tartar. The former has a much more deterrent effect on bad ferments than the latter, but when in great excess it also has an unpleasant harshness to the palate. When we add tartaric acid to a must or wine we get an increase of free tartaric acid in the liquid, but at the same time we get a diminution of cream of tartar. The chemical reactions to which this is due are obscure and complicated, but it is partly due to the fact that the more free tartaric acid there is present the less capable the wine is of keeping bitartrate of potash in solution. The addition of tartaric acid always causes, therefore, a deposit of cream of tartar, and therefore the increase in the acidity of the resulting wine is less than corresponds to the amount of acid added. In a general way we may say that we usually find in the wine about two-thirds of the acid added to the must. The amount will vary, however, according to conditions. If added directly to the wine we may increase the acidity by 70% of the acid used.* If added to the must only 47% may be found in the wine,§ while if added to the crushed grapes as little as 25%§ may remain.

There is very little danger of making the wine harsh unless the maximum doses recommended are very much exceeded; and a slight harshness due to good acidity diminishes with age.

Citric Acid.—This acid has been used extensively during recent years to cure or prevent a certain form of the disease of wines which the French call "la casse." Its efficacy in this respect, and the com-

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* Bouffard, A.: "Revue de Viticulture," vol. 10, p. 545.

† Sebastian, V: "Le Sucrage des Vins," p. 46. Montpellier, 1903.

‡ Pacottet: "Vinification," p. 33. Paris, 1904.

§ Fonseca and Chiaramonte, quoted by Pacottet, P.: "Vinification," p. 74.

plete absence of any injurious effect on the wines treated, suggested its use in the acidification of deficient must, before fermentation, in place of tartaric acid. For this purpose it has been found equally efficacious and, from most points of view, superior to tartaric acid. The only objection to its use is the doubt as to the presence of citric acid as a normal constituent of grapes. Some investigators claim that it does exist naturally in grapes in minute quantities, and as only minute quantities are needed, and as the acid is as "innocuous and wholesome as tartaric acid," there seems to be no reasonable objection to its use. It is not and can not be used in any way to increase the quantity of wine made from a given quantity of grapes, but only to improve its quality. Its use can not therefore be considered a sophistication any more than that of sulfurous acid or finings.

Citric acid has several advantages over tartaric. It does not give the harshness to the wine which some tasters find in case of large additions of tartaric. It does not cause precipitation of the cream of tartar, but on the contrary makes this latter slightly more soluble. This, together with the fact that it seems to have a slightly more deterrent effect on bacteria than tartaric, makes it possible to get the same effect with a much smaller amount. From one half to one third the amount is used. That is, for example, where it would be necessary to add 6 pounds of tartaric acid to a ton of grapes, from 2 to 3 pounds of citric acid would be equally effective.

It is essential that the citric acid should be pure. Citric acid is sometimes found on the market, marked for dyer's uses, which is adulterated with oxalic acid. This would be extremely injurious to the wine. There is, however, no difficulty now in getting pure citric acid in quantities at about 30 cents per pound, which is very little more than the cost of tartaric, and which, considering the smaller amounts needed, makes it more economical than the latter. Citric acid of suitable quality is now made in quantity in California from refuse and cull lemons.

Citric acid must not be confused with lemon oil or essence obtained from the skins of lemons and used for flavoring. Pure citric acid has a completely clean, simple, acid taste, without any lemon flavor whatever.

Plaster.—One of the oldest and most widespread methods of aiding the fermentation by increasing the acidity of the must is by the addition of ordinary plaster of Paris or sulfate of lime to the grapes. The plaster is sifted on to the grapes, as they come from the crusher, at the rate of between 4 and 8 pounds to the ton. The practice was formerly almost universal in southern France and similar climates, but it has been greatly restricted by a law passed in 1891, limiting the amount of sulfate of potash in wines to 2 grams per liter.

The effect of the plaster is to cause a better fermentation and to increase the keeping quality of the wine. It aids in the rapid clearing of the wine and increases and brightens the color. The chemical action is somewhat complex, but the final result is an increase in the acidity of the wine and of the sulfate of potash. The lime sulfate acts on the potash salts existing naturally in the wine, forming insoluble lime tartrates, which are deposited, and soluble sulfates and acid sulfates, which remain in the wine. The acid sulfates finally take the potash from the organic salts and become neutral sulfates of potash, setting free the organic acids to increase the acidity of the wine. When plaster of good quality is used it is a very cheap, effective, and easily-applied means of assisting the fermentation, and is greatly in favor among the wine-makers of nearly all warm regions. While very helpful in obtaining a sound, clear wine of good keeping qualities, it gives a certain harshness which is inadmissible for fine wines. Many samples of plaster, moreover, contain carbonates, which make its use very unreliable, and if present in any considerable quantities neutralize more of the natural acidity of the wine than is set free by the sulfate.

The question of the harmful effects, on health, of wine containing sulfate of potash is still in dispute. The law in France, however, limiting the amount that a commercial wine may contain to 2 grams per liter, makes impossible the use of enough plaster to have the desired effect on the fermentation. For this reason its use is much more restricted than formerly. Some wine-makers use it in conjunction with tartaric acid, using as much plaster as possible without exceeding the legal limit of sulfate in the wine, and making up the deficiency with tartaric acid.

Phosphates.—Latterly many wine-makers in Algeria have been using bi-basic phosphate of lime in the same way as plaster. It is sifted on to the crushed grapes in the same way and produces very much the same effect. It is superior to plaster, as it does not give the harshness due to the latter, and does not increase the sulfates. Acid phosphates of potash are left in the wine and the lime is deposited as neutral lime tartrate. Nothing injurious is left in the wine, and the phosphates doubtless aid the completion of the fermentation. It has, however, the same defect of being unreliable, as its action is very variable and it is impossible to foretell the effect of a certain dose.

CONTROL OF FERMENTATION.

MODIFYING THE TEMPERATURE.

All the fermentations, good and bad, to which must or wine is liable are caused by micro-organisms which get into the liquid either from the outside of the grapes or from the crushers, casks, etc., with which the liquid comes in contact. These micro-organisms, which thus get into the must, consist of yeasts, molds, and bacteria of a very great number of kinds. Few of these kinds, however, can grow in the must, and under the best conditions of wine-making practically none grow but the true wine-yeast. A perfectly clean or pure fermentation is one in which no micro-organism takes part except the true wine-yeast. This is the ideal condition toward which the wine-maker's efforts should tend. It is, however, by no means essential for the production of good wine that this condition should be reached. All that is necessary is that the true wine-yeast should vastly outnumber all the others, and that nothing should interfere with its healthy and complete action. In the finest château wines, molds and false yeasts occur in the first stages of fermentation, but the conditions of wine-making are such that they have little or no perceptible effect on the must before the true wine-yeast commences its action. This action soon overcomes all others and, if nothing interferes with it, the wine is given a stability which makes it a simple matter to prevent all ulterior action of injurious fermentative agents.

The main problem of wine-making, then, after we have obtained the best possible raw material, is to produce a clean fermentation. This is to be accomplished in one or both of two ways: (*a*) by establishing conditions favorable to the growth of wine-yeast and unfavorable to the growth of the other organisms; and (*b*) by eliminating the other organisms and having as little present as possible in the must but pure wine-yeast. One of the most essential conditions is established when our raw material is of proper composition, that is, when the various substances in the grapes, especially the acid and sugar, are in the proper proportion. This is all that is necessary in a cool climate to insure a clean fermentation if the presence of too many unfavorable fermentative organisms is prevented by ordinary care and cleanliness. In a hot region, on the other hand, however favorable the composition of the grapes and however cleanly the methods of handling them, a thorough, clean fermentation is rarely obtained unless we control other conditions. The principal of these conditions is the temperature. The *use* and *necessity* of a high temperature to properly extract the grapes have already been pointed out. The *danger* of high temperatures consists principally, in practice, in their effect on the fermentative organisms.

The injurious effects of too much heat during fermentation are of two

kinds, which should be carefully distinguished. In the first place, high temperatures encourage the growth of the bacteria which cause most of the spoiling of wine. In the second place, the chemical actions which the yeast brings about in the must at a high temperature are different from those which it causes at a low temperature. The first effects would be prevented by any means which excluded the presence of bacteria in the fermenting must; the latter are dependent only on the yeast. It is possible to ferment completely all the sugar in any sterilized must which does not contain more than 26% at any temperature between 15° C. (59° F.) and 35° C. (95° F.); but the qualities of the wine made at the two temperatures will be very different. Leaving out of account the extractive effects, a wine fermented near the lower limit will be smoother, fresher, and contain more alcohol and bouquet than one fermented near the higher. In practice, a wine fermented at the higher temperature may be more valuable on account of the greater color, tannin, and body it contains, if these latter characteristics are what constitute its main value.

It is the failure to properly distinguish between these two effects of heat that causes the wide discrepancies between the figures given by various authorities as to the most favorable temperature for wine-making. The finest Rhine wines are kept at about 15° C. (59°F.) during the greater part of the fermentation, while in Algeria it is considered, by most wine-makers, advisable to allow the temperature to rise to 35° C. (95° F.). In the former case the most valuable characteristic of the wine is its bouquet and aroma, which would be destroyed at high temperatures, while in the latter the color, body, and tannin, which constitute the main value of the wine, would not be sufficiently extracted from the skins at a lower temperature. In the Médoc and Burgundy districts it is considered desirable to keep the wine during fermentation at between 25° and 30° C. (77° and 86° F.). This is low enough not to destroy either the freshness or the bouquet, and high enough to extract the skins sufficiently with the thorough stirring and long maceration practiced in these regions.

In hot regions, like those of Algeria, and most parts of California, all considerations give way to the necessity of finding means of making a *sound* wine, which is the first essential. For this purpose the temperature will in these regions nearly always rise too high unless means are taken to prevent it.

COOLING DEVICES (PHYSICAL).

The temperature to which the fermenting grapes rise is determined by the heat they contain when crushed, *plus* the heat generated by fermentation and *minus* that lost during the process by radiation and conduction. The warmer the grapes and the more sugar they contain, therefore,

the higher the temperature will rise. The smaller the fermenting mass, the cooler the air, the greater the conductivity of the vats, and the slower the fermentation, the less the temperature will rise. Gathering the grapes only in the early morning, or leaving those gathered in the hot part of the day exposed to the night air before crushing, is a very effective way of controlling the temperature in small cellars. In large cellars this is impossible, owing not only to the practical difficulties of finding receptacles for the grapes, but to the fact that however cold the grapes are crushed, the temperature of large masses will rise above the danger point unless the heat of fermentation is eliminated in some way. Professor Bouffard* has shown experimentally that 180 grams of sugar give out at least 23.5 calories during fermentation. This means that 22% of sugar in a fermenting must is capable of generating enough heat to raise the temperature about 90° F. If none of the heat were lost, therefore, a must containing 22% of sugar and commencing fermentation at a temperature of 60° F. would reach 100° F. and "stick" while it still contained 12% of sugar. In practice some of this heat is always lost, but with hot weather and large vats it shows that it is possible for the fermenting must to "stick" however low in sugar-contents it may be, and however cool the grapes are when crushed. Cooling the grapes or must, therefore, is only a partial remedy, and quite insufficient to insure thorough fermentation unless supplemented by some other means.

Aids to Radiation.—Any means which promotes the radiation of heat from the fermenting mass tends to moderate the rise in temperature. One such means is the use of small fermenting vats. The smaller the vat the greater will be the surface from which heat radiates in proportion to the volume of the mass of grapes. For example, a fermenting vat of the ordinary form, containing 100 gallons, will have a radiating surface, reckoning the top, bottom, and sides, of about 31 square feet, or .311 square foot for every gallon of crushed grapes it contains, while one of 1,000 gallons will have about 144 square feet, or .145 square foot per gallon, and one of 10,000 gallons about 670 square feet, or only .067 square foot for every gallon. How little the radiation from even the smallest vats used in commercial cellars can be depended on to keep the temperature below the danger point is familiar to every practical wine-maker. Numerous experiments made at Berkeley make this point certain.† To quote one: Two hundred pounds (about 25 gallons) of crushed grapes were placed in a small vat and allowed to ferment in the ordinary way with three stirrings daily. The temperature of the room varied between 72° and 75° F., and the grapes showed 63° F. when

* "Progrès Agricole et Viticole," vol. 24, p. 345.

† E. W. Hilgard: "Methods of Fermentation," p. 15. See exp. 792, Report of Agricultural Experiment Station, Berkeley, 1888.

crushed. Notwithstanding these favorable conditions of cool grapes and small vat, the temperature rose to 94° F. during fermentation. The grapes contained about 24% of sugar, which, according to Bouffard's tests, would produce enough heat in fermenting to raise the grapes from their initial temperature of 63° F. to about 120° F. Radiation thus got rid of 24° F. by the time the fermentation reached its maximum. In a 10,000-gallon vat radiation could have removed, providing all other conditions were the same, only one-seventh of this amount, and even in a 1,000-gallon vat only three-tenths, which would not have been enough to prevent arrest of fermentation long before the sugar was all gone.

Vats smaller than 1,000 gallons are not practicable, even in small cellars, so that control of temperature by diminishing the size of the vats is incomplete and impracticable for California conditions. The same may be said of vats of special forms. Very high, narrow vats such as are used by brewers, or very wide, shallow vats as used in some wineries, radiate more heat than vats of the ordinary form; but the difference is so little under ordinary conditions that it can not be depended upon to prevent "sticking." A 3,000-gallon vat with a depth of 6 feet presents a radiating surface of about 313 square feet, while one of the same capacity with a depth of only 3 feet has 388 feet of radiating surface. The difference in radiated heat is no doubt greater than is indicated by these figures, as most of the radiation takes place from the upper surface of the pomace, which in the shallow vat will have an area of about 125 square feet, and in the deep vat only about 55 square feet. The difference is not enough, however, to keep the temperature sufficiently low, except in small vats and in cool weather.

Various forms of gratings for submerging or dividing the pomace have been in limited use as aids to cool fermentation. They are attempts to counteract the tendency of the pomace to rise to the top and form a semi-dry "cap" where the heat becomes excessive, even when the must below keeps comparatively cool. Some of these gratings keep the pomace near the bottom of the vat, where it can not become hotter than the must above, owing to the tendency of the cooler must to sink on account of its greater specific gravity. Others are arranged with the object of promoting the continual circulation of the must through the cap, and thus preventing any part becoming hotter than the rest. These appliances are all very troublesome to use, and at the best are only palliatives. Frequent stirring (foulage) of the fermenting mass is almost equally effective and is more easily applied.

An ingenious method of cooling, at one time discussed a good deal and tested to some extent in Algeria, is that of Toutée. It is based on an attempt to increase the heat radiation from the sides of the vats. With the ordinary wooden vat and still more with stone or concrete vats, there is very little radiation, except from the top of the grapes exposed

to the air. Toutée constructed vats of metal, where the radiation from the sides was so much increased that, except in warm weather, white must was kept sufficiently cool in 3,000-gallon vats. With red grapes, owing to the presence of the pomace, the effect was less, unless continued stirring or pumping-over was practiced. A vital defect of the system was its cost and the necessity of replacing the vats on hand.

"*Pumping-over*" is an operation resorted to very frequently in Algeria and France as in California for promoting a dilatory fermentation. Its rationale is not always, however, well understood. It is not properly a method of cooling. In fact, it generally has the other effect. The only case in which it really cools the must is near the end of the fermentation, when it is desirable to prevent cooling in order not to check the action of the yeast. It is often, nevertheless, very effective in producing a thorough fermentation. This it does, not by cooling the must, but by providing the yeast with an abundance of oxygen, which strengthens and stimulates it and enables it to attack the sugar more forcibly. It is very effective and useful at the beginning of the fermentation in cool weather, or when real cooling means are applied as well. In hot weather it is more likely to increase the trouble, and toward the end of fermentation it entails a loss of alcohol and a vapid taste, which may more than offset any benefit derived.

Attemperators and Refrigerators.—The failure, in the majority of cases, of all the methods previously discussed, long ago led the wine-makers of Algeria to look for some more effective and reliable method of controlling the temperature. This they have found, after many trials, in two or three forms of machines known by the above names. An *attemperator* is an appliance—usually a long spiral tube—which is placed in the fermenting-vat and through which *water* or other cooling liquid is run. A *refrigerator* is an appliance—also usually a spiral tube—outside the vat, through which the *wine* is run, and which is cooled by a cold liquid on the outside. Innumerable forms of both classes of machines have been tested, but only a few have come into general use.

A very efficient form of attemperator is that used at the Government wine cellar of Constantia in Cape Colony and in some Australian cellars.

Fig. 2 will make clear the principles involved. Each vat is furnished with a grating by which the pomace is kept submerged several inches below the must, and with a small pump for bringing the must from the bottom to the top. When the temperature rises to the point which it is not desired to exceed, a copper coil is placed in the must above the grating and attached to a water tap. Cool water running through this coil soon brings down the temperature of the supernatant must. In the meanwhile the pump, which is attached to a shaft which

works all the small vat pumps, is started, and a continuous but slow flow of liquid is established, which is cooled as it comes in contact with the coil on top and cools the pomace as it passes through. This arrangement gives very perfect control of the fermentation, with comparatively little labor. In vats of one or two thousand gallons the temperature can be kept at any point desired, and the extraction of the pomace can be increased or diminished very considerably by the more or less constant working of the vat pumps. Whether the control of temperature or the extraction of the pomace would be as complete in large vats where the pomace cap beneath the grating was very thick, is doubtful.

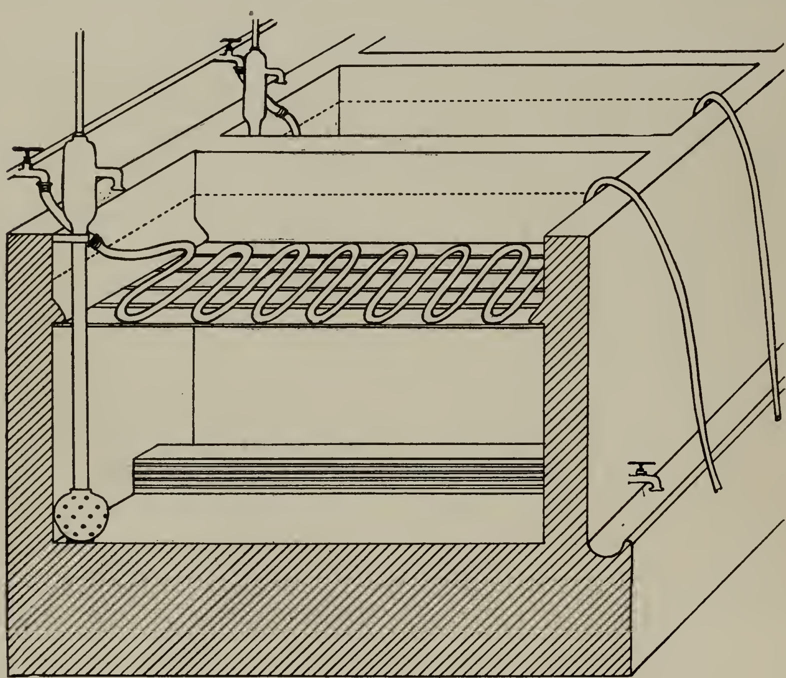

Fig. 2. Cooling device for fermenting-vat.

The method, however, is excellent in small or medium-sized cellars, where the object is to make wine of high quality. Its principal objection is the initial expense.

Cheaper attemperators have been made consisting simply of coils of copper or varnished galvanized iron piping placed around the inside walls or in various other positions in the vats. They are all efficient enough for the cooling of white wine where there is no solid matter present, but are quite inadequate for the case of red wine, and fail almost completely to prevent undue heating in the cap, except in small vats where continuous stirring can be practiced.

Refrigerators.—Appliances of many forms arranged for the cooling of the fermenting must outside the vat have been devised and tested. Only two types are in extensive use at the present time, however. The more common of these is that originated by Müntz and Rousseau,* which is made by several manufacturers of cellar appliances. It consists of a series of horizontal, superposed copper tubes, connected in such a way that the warm must enters at the bottom and emerges at the top. The cooling is obtained by causing water to drop or flow over the tubes from top to bottom. This form (Fig. 3) is useful especially where water is scarce, and is the type used almost exclusively in Algeria. There is probably not a single large cellar in Algeria, Oran, or Constantine which does not possess one or more of these machines, and by their use the production of a sound, completely fermented wine has become possible in all cases.

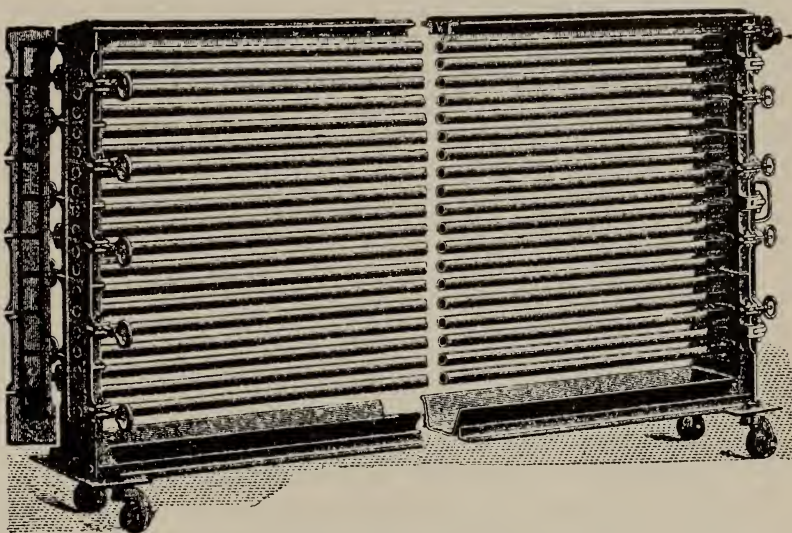

Fig. 3. Algerian type of refrigerator.

The amount of cooling necessary is indicated by the following example:

Grapes containing 20% of Fermentable Sugar.

Temperature of grapes when crushed	20° C.
†Heat liberated by fermentation of 20% of sugar	26° C.
Total temperature units	46° C.

In order, then, to prevent the temperature of the fermenting must from rising above 35° C., it is necessary to remove 11° C., or approximately 11 calories. That is to say, when the temperature reaches 35° C., if it is

* See Bull. 117, Calif. Agr. Exp. Station.

† Calculated by using Prof. Bouffard's figure of 1.3 calories for each per cent of sugar.

cooled to 24° C. the sugar will have all disappeared by the time it reaches 35° C. again, as shown by the following table:

Temperature.	Degrees of Temperature.		Per Cent of Sugar.	
	Gained.	Removed.	Removed.	Remaining.
20°				20.0
35°	15		11.5	8.5
24° cooled		11		
35°	11		20.0	0.0

This supposes that no heat is abstracted except that taken by the cooling machine. In practice, even in large concrete vats, a certain amount of heat is lost by radiation, so in the case above it would not be necessary to remove quite 11 calories. In California, with our sweeter grapes and hotter weather, it would be necessary to remove more heat than in Algeria and generally to cool twice. The following may be considered an average example:

Grapes containing 22% of Fermentable Sugar.

Temperature of grapes when crushed	70.0° F.
Heat liberated by 22% of sugar	51.7° F.
Total temperature units	121.7° F.

In order to prevent the temperature rising above 95° F. it would be necessary to remove heat equivalent to 26.7° F. or, allowing for a certain amount of loss by radiation and conduction, the cooler would have to remove about 20° F. It would be easier and probably more desirable to remove this by two coolings of 10° F. each than by a single one of 20° F.; easier, because it requires less time and less water of a given temperature to cool must from 95° to 85° than from 85° to 75°, and probably more desirable, as some observers claim that too much cooling at one time delays fermentation. The relation of the temperature with the disappearance of the sugar would then be somewhat as follows:

Temperature of Wine.	Degrees of Temperature.		Per Cent of Sugar.	
	Gained.	Removed.	Removed.	Remaining.
70°	0	0	0	22
95°	25		12	10
85° (first cooling)		10		
95°	10		17	5
85° (second cooling)		10		
95°	10		22	0

These figures in the temperature columns of the foregoing tables must not be understood to represent the actual temperatures found in practice. At no time would there be a fall of temperature from 95° to 85° F.

of the whole mass of fermenting grapes. This difference of 10 degrees simply represents the amount of heat which it is necessary to remove during one cooling, and is useful in indicating the amount and the temperature of the water needed. While the cooling is going on, fermentation and the production of heat continue, so that though the must passing through the cooler may be reduced 10 degrees or more, the whole mass in the vat will be reduced very much less or even not at all. The good effect consists, in the latter case, not in cooling the fermenting mass, but in preventing its temperature from rising any higher.

A description of the common Algerian practice in cooling will make this clearer. As a rule, the fermenting-vats are made of such a size that two of them will contain exactly the amount of grapes gathered in one day. One is filled in the morning and another in the afternoon. When the temperature of the first vat reaches 35° C. the faucet at the bottom is attached to a pump and the hot must passed slowly through the cooler and back into the vat again. The must as it leaves the cooler may have a temperature of 25° C. to 30° C., but it is fermenting and producing heat meanwhile as are the other contents of the vat, so that there may be very little if any apparent reduction of temperature in the vat. The sugar, however, is disappearing, until a time comes when, though the temperature of the vat may still be nearly 35° C., there is not enough sugar left in the must to heat it above that point. In fact, the usual plan in Algeria is to start pumping through the cooler as soon as the must reaches 35° C., and to continue this pumping until the fermentation is practically finished, that is, until only 2% to 3% of sugar is left. If the temperature is then, say, 34° C. and has never exceeded 35° C., there is no danger of the vat "sticking." This pumping through the cooler occupies eight or twelve hours for each vat, and is kept up night and day. This explains the arrangement of having two vats filled per day. One is cooled at night and the other during the day. Every vat is cooled, and cooled but once. When the weather is warm and the grapes very sweet, the wine is kept going through the cooler for a longer time. On the other hand, cool weather and grapes of low sugar-content necessitate less time. The size of the vats, the size of the cooler, and the amount of water should be so calculated that twelve hours' pumping in the hottest weather with the sweetest grapes expected will remove the necessary amount of heat from half the grapes crushed in one day. In hot weather, when the grapes are warm when crushed, it will be necessary to cool twice; but the total time of both coolings should never exceed the twelve hours, or an extra machine should be kept in reserve for exceptionally hot weather.

In order to show what a cooler of this type may be expected to do under California conditions, the following figures have been calculated on the basis of actual experiments made.* The estimate has been

* "Revue de Viticulture," vol. 7, p. 365.

made for a cellar receiving a maximum of 100 tons a day in hot weather.* In cool weather more could be handled:

Cooling by Müntz and Rousseau's Machine.

(Average case.)

Grapes containing 22% of sugar, capable of developing	51.7° F.
Temperature of grapes at crushing	70.0
Total degrees of temperature	121.7
Maximum temperature desired	90.0
Number of degrees necessary to be removed	31.7
Less 6.7° F. from radiation	25.0
Temperature of water	65.0

(If the must is cooled to 77½° F. as soon as it reaches 90° F. it would require two coolings to remove the necessary 25 degrees.)

Wine to cool in 20 hours	24,000 gallons
Water required	48,000 gallons

Machines needed, 1. (Capacity of M. & R. machine, 2,400 gallons per hour.)

If the grapes contained 24% of sugar and their temperature at crushing was 80° F. and that of the water available 70° F., which is an extreme case, two machines would be necessary and twice the amount of water. The cost of the water is merely nominal if the cellar is near an irrigating ditch. Recent investigations of pumping plants in practical use in irrigation show that on the average 300,000 gallons can be raised 10 feet for about $1.†

For a cellar of the size supposed, viz: one crushing about 100 tons of grapes per day, two coolers would be necessary, of the capacity of Müntz and Rousseau's largest size and an available supply of about 100,000 gallons of water per day, the temperature of which should never exceed 70° F. This would make it possible to prevent the wine ever surpassing 90° F., even in the hottest weather, and under average conditions not more than half the water and only one machine would be used.

Most of the large cellars of California are situated where they can obtain an abundant supply of water by pumping. This is especially true in the hotter regions, where irrigation is practiced. In this we have a great advantage over Algeria, where water is very frequently scarce. The various ingenious devices invented in Algeria for cooling the water before using would be of little use here, because it would hardly ever be necessary to use the same water twice, and cool water can be obtained in nearly all cases. Regular observations made by the Irrigation Department of the University of California show that the temperature of the main irrigating canals in the San Joaquin Valley during the wine-making season varies between 60° and 70° F., which is quite cool enough for the purpose.

* Newer forms of this type of cooler are even more efficient. See "Progrès Agricole et Viticole," vol. 30, p. 19.

† S. Fortier: Circular No. 59, Office of Experiment Stations, Washington, D. C., p. 10.

Another type of cooler commonly used consists of a long copper or galvanized iron pipe laid in a long trough. The wine is pumped through the pipe and the water flows in the trough in the opposite direction. The device is simple, easily constructed at the cellar, and is not costly. Its main defect is that it does not thoroughly utilize the cooling capacity of the water, and much more water is necessary. Where large quantities of cool water are available, as near a main irrigating canal, it should be very useful. A good example of this type of cooler is in

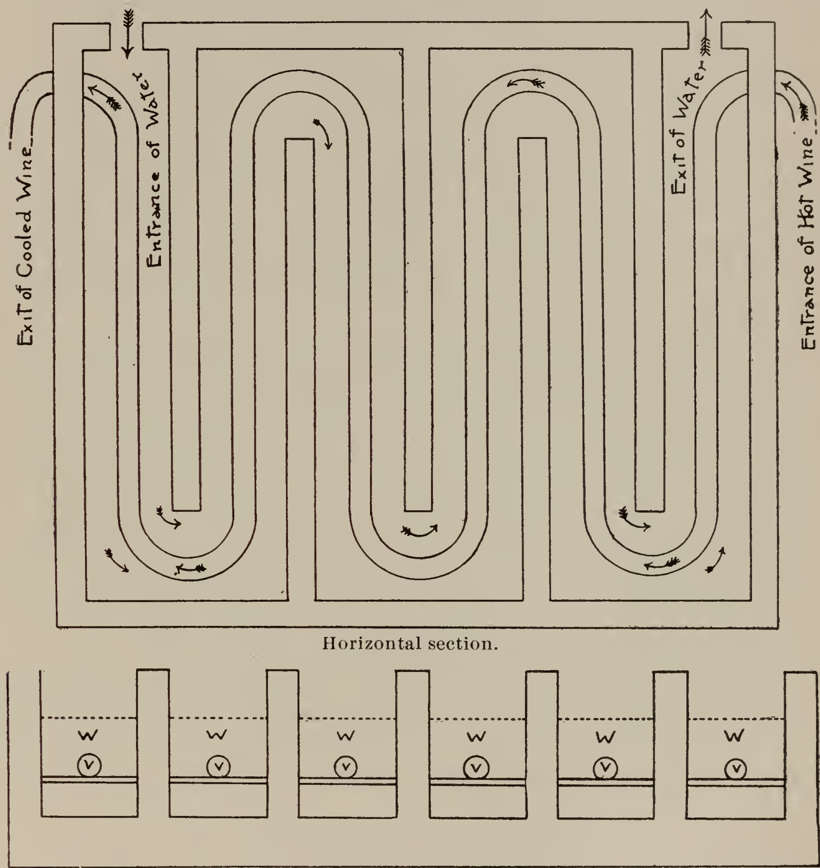

FIG. 4. Plan and section of a wine cooler at Le Grand Craboules, Narbonne.

operation at the cellar of M. Gaston Gautier near Narbonne. At this cellar is made about 500,000 gallons of wine yearly. The trough is made of six walls of concrete about 2 feet high and 4 inches thick, so arranged that the water flows from one end to the other in a zigzag course. The galvanized iron* pipe through which the wine runs is laid near the bottom of this trough. The machine is said to run all the

*The pipe should be *tinned*, not "galvanized," as in the latter case the zinc covering will be quickly *corroded* by the acids of the wine, and zinc will contaminate the wine.

season without cleaning, and remain effective to the end. At the end of the season the wine pipe is taken apart at the joints and cleaned. Such a cooler as this could be very easily constructed on the bank of an irrigating canal, or the piping might even be placed directly in the canal.

Ice.—The cooling power of ice might be used very effectively to prevent hot fermentations, if it could be obtained cheaply enough. For white wine, it is easily applied by placing the ice in a tinned copper tub floating on top of the must. The hottest must rises to the top and is cooled by contact with the tub and falls to the bottom. This creates a circulation of the liquid, which maintains a uniform temperature in all parts of the vat. For fermenting masses of crushed grapes this method is not applicable. In this case the ice could be used to cool the water used with an ordinary refrigerator. Five pounds of ice will reduce 100 gallons of must about one degree Fahrenheit. To reduce the must 20 degrees Fahrenheit, as in the case instanced on page 40, it would require over one pound of ice for every gallon of must. This may be taken as about the average cooling necessary, so that for every ton of grapes, when used for white wine, 200 pounds of ice would be needed, and about 300 pounds for the same amount of grapes when used for red wine. If used in connection with a water refrigerator, simply to increase the coolness of the water where only warm water was available, would require under ordinary conditions about the same amount.

The cost of cooling for ice alone would amount to about $1.50 per ton of grapes, reckoning ice at ½ cent per pound, which is about 1 cent a gallon for the wine made. This is much more than the whole cost of cooling, including labor, where it is possible to get cool water.

The method, which has been tested in California, of placing the ice directly in the vat with the idea of cooling and reducing the sugar at the same time, is quite inadmissible. The amount of ice necessary would introduce far too much water into the must.

CHEMICAL COOLING DEVICES.

The rise of temperature in a vat of fermenting grapes is due to the fact, already noted, that more heat is produced in a given time by fermentation than is lost by radiation and conduction in the same time. The heat produced is limited by the amount of fermentable sugar present; the heat lost, by the time of fermentation. If the fermentation is rapid the excess of heat produced, over that lost in a given time, will be great, and the rise of temperature correspondingly great. If on the contrary the fermentation is slow, the excess will be less and the rise of temperature less. If the fermentation is slow enough, the heat lost may equal the heat gained and no rise of temperature at all take place.

Anything, therefore, which retards fermentation will lower the maximum temperature to which the grapes will rise. Various substances may be added to the must which have this effect of retarding the course of fermentation. The only one which has come into practical use is *sulfurous acid* in some form. There are two sources of this acid which are at present extensively used in wine-making. When sulfur is burned it produces sulfurous acid gas. One pound of sulfur on burning yields two pounds of sulfurous acid. The other source is a salt of sulfurous acid, *potassium meta-bisulfite*, often sold commercially under the incorrect name of potassium sulfite. When this salt is placed in must or wine it is broken up by the acids in the wine, and yields sulfurous acid equal to 57% of its weight. The cost of the sulfite is about 23 cents per pound in France, and that of sulfur less than 2 cents. As the former yields only one fourth as much sulfurous acid as the latter, the cost of material is about fifty times as great. The difference in cost of material is in many cases, however, counterbalanced by the greater ease with which the sulfite can be used.

Sulfur.—The fumes of burning sulfur have long been used in the manufacture of white wine in all wine-making countries. The finest white wines of the Rhine and Gironde are sulfured in this way very heavily. Some of the finest of the former contain as much as .20 per mil. to .26 per mil. of sulfurous acid. Sauternes and Graves of the Gironde contain similar amounts. As this is many times as great as is needed for controlling the temperature, and as practically all that is used disappears from the wine during fermentation, the question of the legality or wholesomeness of the practice does not come into consideration in the making of ordinary wine. While the use of sulfurous acid has other advantages, especially in the making of the wines mentioned, in ordinary cases one of the chief benefits is the moderation of the rate of fermentation and the consequent lower temperature. For this purpose it is used extensively in southern France and to a less extent in Algeria. To give an idea of the moderation of temperature realizable in the fermentation of red wine, the following example may be given:* Two tests were made with two closed vats of 3,750 gallons each. One vat of each pair was sulfured and both filled at the same time with crushed Carignane grapes. In Nos. 1 and 3, 2.2 pounds of sulfur was burned before filling. When the temperature of these vats reached 86° F. the fumes from 1.1 pounds of sulfur were pumped into the must. Twenty-four hours later this treatment was repeated. Owing to the method of introducing the sulfur fumes there is no way of determining how much the must absorbed, but probably not more than 10% or 20% of the amount produced.

* "Progrès Agricole et Viticole," vol. 29, p. 536.

Casks Nos. 2 and 4 were treated in every way the same as Nos. 1 and 3, except that no sulfur was used. The following table shows the results:

	Maximum Temperature	Drawn off at	Sugar Remaining.	Alcohol in Wine at 2 Months.
Vat No. 1, sulfured	93°	8 days	0	13.5
Vat No. 2, no sulfur	102	9 days	2	13.0
Vat No. 3, sulfured	95	9 days	0	13.9
Vat No. 4, no sulfur	104	10 days	2.5	13.3

In spite of the retarding effect of the sulfurous acid the fermentation in the sulfured vats finished first. Though the fermentation in the unsulfured vats was most rapid at first, the great heat developed stopped the action of the yeast before all the sugar had disappeared, so that the last 2% of sugar required several weeks to ferment out.

The alcohol in the sulfured wines was about a half per cent higher than in the others, a difference due in great part probably to loss from evaporation while pumping-over the latter at a high temperature.

The amount of sulfurous acid needed to delay fermentation is indicated by some tests made by Roos.* Must containing .05 per mil. of sulfurous acid fermented three fourths as fast as without any, and must containing .1 per mil. fermented less than one half as fast. These figures can be used only as indications of where to commence trials in practice, for the amount necessary will depend on a variety of conditions which differ for every cellar, viz, composition of must, temperature of grapes and cellar, amount of aëration, kind and quantity of yeast present, and size of fermenting-vats. The amount necessary depends especially on the amount and kind of yeast present. If the sulfurous acid is added before fermentation starts, a small amount delays fermentation considerably. In this connection Roos † gives the following figures as a guide to the use of sulfurous acid in clearing white must before fermentation:

To delay 10–12 hours	.030 gram per liter.
To delay 18–24 hours	.050 gram per liter.
To delay 48–60 hours	.075 gram per liter.
To delay 5–6 days	.100 gram per liter.

These results indicate that freshly expressed must, to which has been added the amounts of sulfurous acid mentioned, will not show perceptible fermentation until after the times mentioned. If these amounts of the acid were added to must in full fermentation they would not stop the action of the yeast, but would simply diminish its rate, as in the experiments mentioned on page 45. Therefore, the larger the amount of yeast present the more sulfurous acid is needed to delay or check fer-

* "Progrès Agricole et Viticole," vol. 29, p. 225.

† Roos: "Industrie Vinicole Meridionale," p. 234.

mentation. The kind of yeast also influences the result. Some yeasts are much more sensitive to the action of the acid than others. Part of the good effect of a preliminary sulfuring of the must is that the true wine-yeast is more resistant to sulfurous acid than most of the other organisms present, and musts thus treated are therefore likely to undergo a purer fermentation. Yeasts may even be selected with a special resisting power, as in the process described on page 56.

The possibilities of cooling by the use of sulfurous acid are of course limited by the amount of possible loss of heat by radiation. In warm cellars, or in very hot weather, the temperature will run up too high in spite of sulfuring. The same is true of fermentations in large vats. The method is, therefore, of limited use, and while very effective in small cellars and cool climates is usually insufficient under other conditions.

In the south of France the white musts are always treated with the fumes of burning sulfur. The old method was to burn a certain quantity of sulfur in each cask before introducing the must. Now the must is usually passed through a "sulfurizer" and then pumped into the casks. In both methods there is great uncertainty as to how much sulfur fumes are absorbed. In the first method only a portion of the fumes are taken up by the must, the remainder being expelled with the air as it is forced out of the cask by the must. The difficulty is not so great, however, in practice as it seems *à priori*.

If a small quantity of sulfur is burned, nearly all the fumes are absorbed, while if a large quantity is burned, the greater part escapes. Practical tests, under ordinary cellar conditions, show that if all the sulfur possible is burned in a small cask, the must when introduced in the ordinary way through a hose will absorb about .1 per mil. of sulfurous acid. If only one seventh of this possible amount is used the must will absorb .05 per mil., or half as much. That is, if we burn 2.7 ounces of sulfur in a 100-gallon cask it will have only twice the effect of burning .4 ounce. The amount necessary for defecating the must or for moderating the heat of fermentation lies between these two extremes of .1 per mil. and .05 per mil., so that when the fermentations take place in small casks the rough guess of the cellarman as to the quantity of sulfur to burn is usually near enough for practical purposes. With large casks this is not always true, as the sulfur fumes are absorbed more completely. The absorption, however, is not complete enough, even in this case, to make the amount of sulfur burned a sufficient measure of the amount of sulfurous acid introduced into the must.

Many ingenious devices exist for causing the must to absorb all the sulfur fumes produced and so to make it possible to introduce an exact amount. These devices are of two types: In one, the must passes through an apparatus placed in the bunghole of the cask, so constructed that all the fumes coming out of the cask pass through the incoming

must and are therefore absorbed. In the other, the cask is filled first and the sulfur fumes are then forced into the cask by means of a pump. Most of the devices of the first type are cumbersome, troublesome to put in place, and are little used. One of the simplest is the *Brise-jet* of

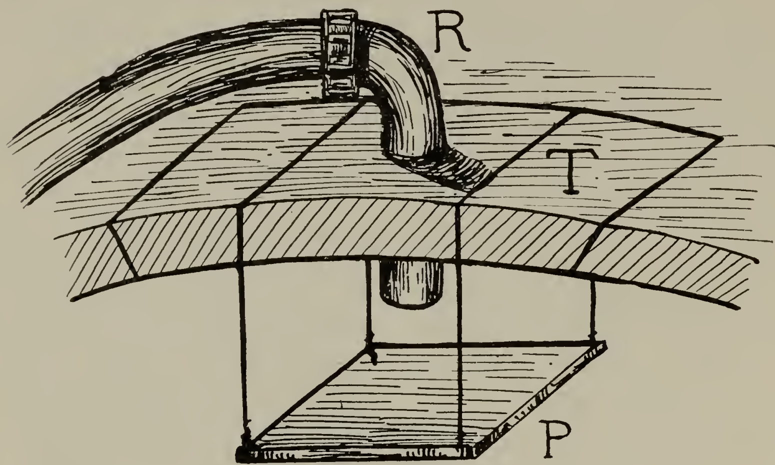

FIG. 5. Brise-jet.

R, hose for entrance of wine; T, cover of manhole to which is attached by cords a small piece of wood, P, on which the entering wine strikes and is broken up into a spray.

Roos, shown in Figs. 5 and 6. By means of this simple device the incoming stream of must is thoroughly broken up into a spray, and tests show that only from 1% to 5% of the sulfur fumes escape. This is quite close enough for practice. It can not, of course, be used except where

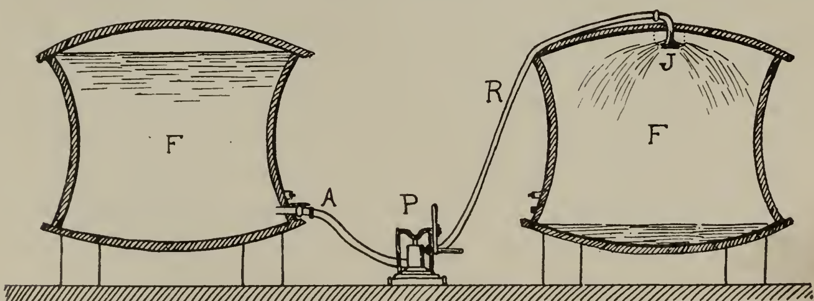

FIG. 6. Illustrates method of causing absorption of sulfur fumes by means of Brise-jet. F, cask containing wine or must to be sulfured; A, suction hose of pump, P; R, delivery hose conducting wine into cask, F, in which sulfur has been burned; J, Brise-jet.

there is a manhole on the top of the cask. For casks with only a bunghole on top a long tube pierced with small holes may be adapted to the end of the hose, but the absorption is then not quite so complete.

The second type of sulfurizer is exemplified by Fig. 7. The correct amount of sulfur is weighed and placed in an iron pan beneath a cask from which one head has been removed. The suction hose of a pump

is then attached to the bunghole of the inverted cask, and as the fumes are given off they are driven by the pump into the must, preferably through a hose inserted through the upper bunghole. This method is very effective for introducing large quantities of sulfurous acid, but is little used. The hot sulfur fumes are apt to injure the hose and pump and the method is troublesome to use in large cellars.

The sulfurizers used in most of the cellars which make large quantities of white wine are similar in principle to the one shown in Fig. 8. An examination of the figure (8) will make clear the principle of the machine. The must enters by the hose shown at the upper right-hand corner of the figure, flows from shelf to shelf through the sulfuring cham-

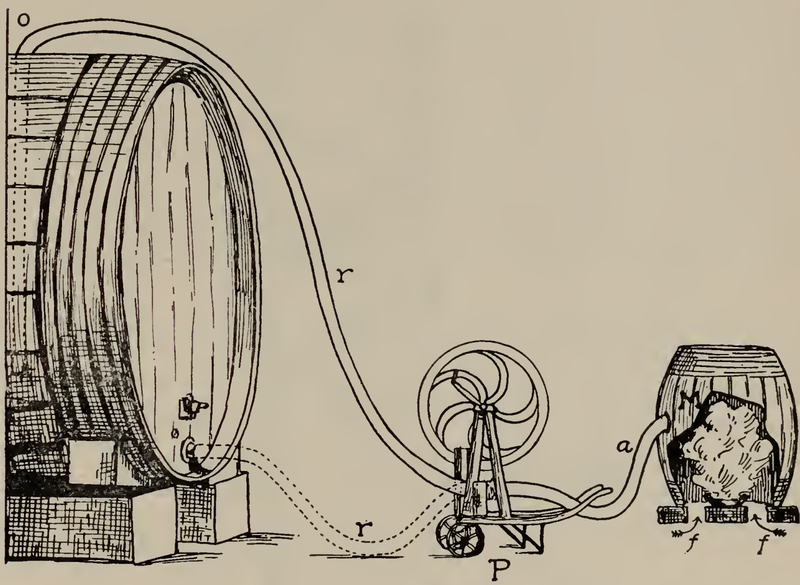

FIG. 7. Method of sulfuring must with a pump.
M, small cask with one head removed, serving as a chamber in which to burn the sulfur; *f*, *f*, openings for entrance of air; *a*, *r*, hose through which the sulfur fumes are forced into the cask of wine by means of the pump, P.

ber into a reservoir below. The sulfur fumes generated in the stove shown at the lower right-hand corner of the figure enter the sulfuring chamber near the bottom and take a zigzag course to the top where the current of air which carries them escapes through a narrow chimney. This arrangement insures a thorough contact between the must and the sulfur fumes.

The sulfurous acid is so completely absorbed in this machine that there is no odor of burning sulfur at the opening O where the air escapes. The quantity of acid absorbed by the must depends on the amount of sulfur burned and the rate at which the must passes through the apparatus. It is possible thus to approximate a certain dose in sulfuring

the must, but hardly more closely than by the old method of burning the sulfur in the casks. The chief merits of the machine are saving of labor and of the inconvenience and difficulty of burning sulfur in the casks, especially when they are large. At the cellar of Villeroy, near Cette, where 1,000,000 gallons of white wine are made annually, all the must is sulfured by two machines constructed on this principle.

Any of these methods can be effectively used in the manufacture of white wine where the dosing of the sulfurous acid has not to be done

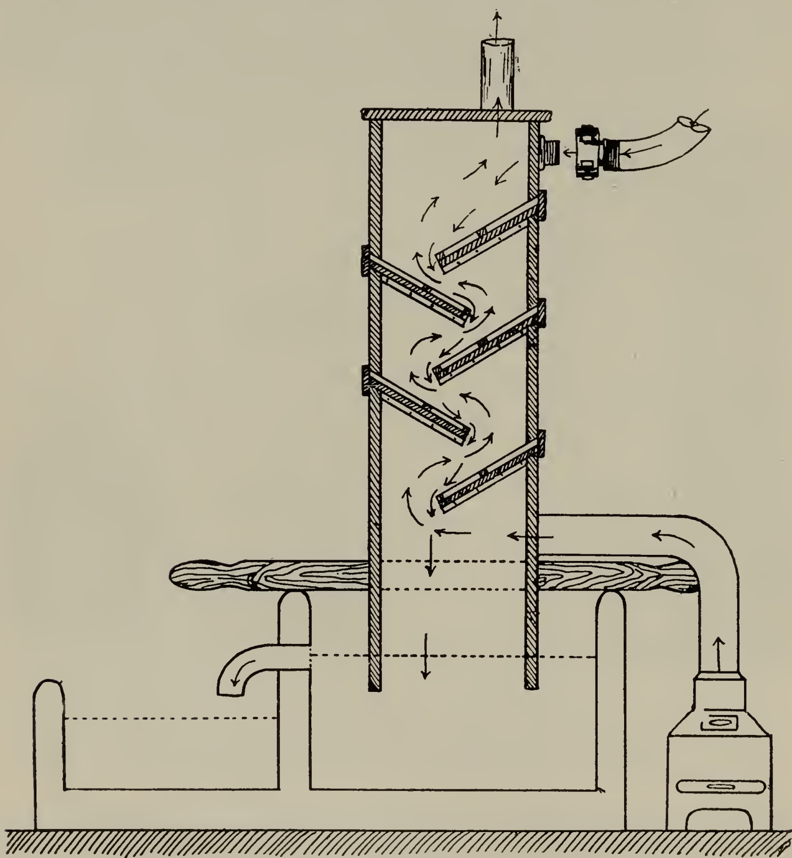

FIG. 8. Paul sulfurizer.

with a great deal of exactness. For red wine they are very imperfect, both because of the greater difficulty of introducing the fumes into the crushed grapes, and of the greater need for precision in the doses.

Sulfites.—Sulfurous acid has a strong bleaching action on many substances, and if used in red wine tends to decolorize it. This decolorizing may be very considerable if large quantities are used, as is shown

by a test made by A. Bouffard.* Various amounts of the acid were added to a wine, and the loss noticed as follows:

Sulfurous Acid per mil.	Loss of Color.	Loss at One Month.
.025	7%	3%
.050	12%	6%
.075	25%	20%
.100	35%	30%

The second column shows the amount of color lost immediately after sulfuring when compared with the unsulfured wine. A month later the difference was much less, especially for the small doses. The loss is in any case, however, much less than appears at first. The color is not all destroyed and reappears to a great extent as the sulfurous acid disappears from the wine either by escaping into the air during racking or by becoming oxidized to sulfuric acid, or by forming various chemical combinations with substances in the wine. Moreover, the color which is left is more brilliant and more stable than that in an unsulfured wine. As there certainly is some loss, however, especially with large doses, it is necessary to use no more than is absolutely necessary to control the temperature. For this reason potassium meta-bisulfite is nearly always used in preference to burning sulfur when treating grapes and must for red wine.

The bisulfite is very easily soluble, and may be dissolved in a little water which is added to the grapes gradually as they are crushed, care being taken to distribute it well in all parts of the vat. To give a dose of .05 per mil. of sulfurous acid it would be necessary to add one-fifth of a pound of sulfite to every ton of grapes. This would cost about 6 or 7 cents. The sulfur necessary for the same dose would cost but a small fraction of a cent, but would be more troublesome and therefore costly to use, besides being less reliable.

POSTPONEMENT OF FERMENTATION UNTIL WINTER.

One of the great advantages that the vineyards of the high Little Atlas mountains and the elevated plateaus of Algeria have is that the weather is cool during the fermenting season. This is due partly to the elevation and partly to the late ripening of the grapes. If it were possible in the warmer parts to prevent fermentation of the grapes until cool weather, it would be comparatively easy to prevent hot fermentations. This can, in fact, be done by treating the crushed grapes with a sufficient quantity of sulfite. The amount necessary depends on the condition and composition of the grapes, the temperature of the cellar, and the amount of yeast present. Clean, acid grapes can be crushed and kept in a cool cellar for months by adding .5 mil. of sulfurous acid or two pounds of sulfite to every ton. Grapes with little acid or which have commenced to ferment, or which are kept in a warm place, would

*Bouffard, A.: "La Casse des Vins," p. 24. Montpellier, 1902.

require more. The smaller amount, however, is sufficient to injure the color of red grapes considerably. While the method might be used for white grapes or must, it is not practicable for red grapes with the present arrangement of cellars, as it would necessitate a large increase of vats or other cooperage.

FERMENTATION IN A COOL LOCALITY.

Large quantities of grapes, crushed grapes and must, are transported from the south of Europe to the north for wine-making purposes. This is not done, however, primarily for transferring them to a climate more favorable to fermentation. Grapes are sent from Italy and France into Germany for the purpose of supplementing the watery, acid, and badly ripened grapes of the latter country, and as part of the raw material of the innumerable vintages fabricated at Hamburg and elsewhere. Some of these grapes are transported in baskets, barrels, or vats as they are gathered, but the greater part are crushed before sending. When the distance is short no precautions are taken to prevent fermentation, but where the distance is over two or three days the crushed grapes and must are usually preserved with sulfurous acid. The amount used is about .4 per mil., or about 1½ pounds of sulfite to the ton. This is sufficient to paralyze all the yeast present and to prevent any danger of fermentation on the journey. Fresh must from sound grapes treated with this amount will usually keep for several months.

There is no doubt that if the grapes of the San Joaquin Valley could be transported to the Bay Region cheaply enough, there would be little more difficulty in fermenting them than the grapes of the coast valleys. This is proved by the wines made at the California Experiment Station cellar from grapes shipped from Tulare. It is simply a question of cost and shipping facilities. The extra freight charges would be considerable, as the weight of the grapes is about two-thirds greater than that of the wine they make. There would, besides, be the cost of boxes or other receptacles. In parts of Italy and Algeria crushed grapes are transported in specially constructed iron tanks on railway trucks. Sulfites could be used only for white wines, on account of the large amount necessary. In any case there would have to be sufficient guaranty that the grapes would not be more than two days from the time they were put on the truck to the time they were placed in the fermenting-vats.

In order to economize in freight charges many attempts were formerly made to concentrate the grapes or must before shipping. No advance seems to have been made, however, over the methods of Springhmühl, which were thoroughly tested in California, and those of Favara in Sicily. The method is fairly successful for the making of sweet wines, but these can be made as well or better in hot countries. For

dry wines the concentrated grapes and must have failed, being little, if at all, better than dried grapes for this purpose.

CONTROL OF THE FERMENTATIVE AGENTS.

The various cooling devices just discussed act, in so far as they prevent imperfect or deleterious fermentations, by controlling the fermentative agents. That is, they keep the fermenting mass at a temperature favorable to the true wine-yeast whose action we want to assist, and less favorable to the bacteria and other injurious organisms whose action we want to hinder. Cooling, however, only *hinders* the growth of the latter, but in no case *completely prevents* it. Under favorable conditions this action is so slight as to be practically inappreciable; under less favorable conditions the freshness and bouquet of the wine may be impaired, or in extreme cases the wine spoiled. These are, however, only differences in degree. If we could find some means of absolutely excluding all organisms from the must except the true wine-yeast, we should get none of the defects due to injurious secondary fermentations under any conditions.

Pure Yeasts.—With this object in view various methods have been devised for sterilizing the grapes and must; that is, of freeing them from all micro-organisms of any kind, and subsequently fermenting them by adding a pure yeast. A pure yeast is a liquid containing no micro-organisms but yeast cells and only one kind of yeast cell. For about twenty years, extensive laboratory and practical tests have been made with these methods, but there is still wide divergence of opinion as to their merits. There is perfect unanimity of opinion as to the value of eliminating unfavorable organisms, but on the value of the use of pure yeast there is much difference of opinion. On one side it is claimed that the character of Château Iquem or of Clos Vougeot may be given to the wine from any grape, or even from apples, wherever grown, by the use of a pure yeast selected from the vineyards which produce these famous wines. Factories are in existence which are ready to supply yeasts from any one of the hundreds or thousands of famous wines of the world, with the implied assurance that they will enable any wine-maker to produce these famous wines anywhere. Much of this is no doubt due to the exaggeration inseparable from advertising. The claims of certain laboratory investigators of pure yeasts, however, fall little short of those of the vendors of pure yeast for wine-making, and are undoubtedly in many cases excessive and misleading. At all events they are not substantiated by results in practice, or by the work of other investigators. On the other hand, it is an equally great mistake to suppose that the purity or selection of the yeast has no effect on the wine. The comparative purity of the yeast is the object of a great part

of the care taken wherever good wines are made, and there is no doubt about the great differences which exist in different yeasts and in their effects on the wine.

It is just here that there is danger in the use of absolutely pure yeasts prepared by modern methods. While it may not be possible to make the difference between a "Rommanée Conti" and a "Château Lafitte" wine by a proper selection of yeasts, there can be no doubt whatever that it is possible to make the difference between a good wine and a bad wine from the same material according as we use an appropriate yeast or an inappropriate one. We can not make good wine from *any* grapes by the use of pure beer-yeast, bread-yeast, or any of the hundreds of yeasts which we can find almost anywhere. Moreover, it is quite possible to select from grapes pure yeasts which have very different effects on the wine in fermentation. Some pure wine-yeasts will not give good results at high temperatures, others at low; some will not cause the fermentation of more than 18% of sugar, others can ferment 26% and so on. If, therefore, we use *pure yeasts* we must use *selected pure yeasts;* yeast selected and tested for the particular purpose in hand.

Most of the pure yeasts distributed in Germany and France have been properly selected, and in spite of the exaggerated claims of the makers, usually give good results when properly used. It would, however, be quite possible to completely spoil wine by the use of a pure yeast not properly selected for the particular must in which it is placed. This is no doubt the reason why pure yeasts obtained from the regions where they are to be used have nearly always given better results than yeast imported from other regions. It is far more likely that a pure yeast separated from fermenting Fresno grapes will prove resistant to high temperatures and capable of fermenting very sweet must, than one separated from grapes grown on the Rhine. The yeasts which exist in any region have undoubtedly been subjected for ages to a process of natural selection which has fitted them for the conditions of that region. Rhine yeast will, therefore, not help us to make Rhine wine in Napa County, unless we can get grapes whose composition approaches those of the Rhine, and can imitate the temperature and other conditions usual in the Rheingau.*

To obtain the best results from the use of selected yeasts in promoting a thorough fermentation or improving the wine in any other way, a more or less complete sterilization of the grapes or must is necessary. Very numerous trials have been made, with this object in view, during the last twenty years. While the question of the degree of improvement to be attained by the use of selected yeast is not yet settled, the

*See, for a good practical example of this:—Report of Viticultural Work, College of Agriculture, Berkeley, 1887–93, pp. 400–402.

attempts at sterilization have brought to light some unforeseen but very important facts regarding the effect of the methods used in the process of wine-making.

Attempts have been made to free must from fermentative organisms in various ways; but only two, so far, have given good results or been adopted in practice. These are sterilization by heat and sterilization with sulfurous acid.

Twenty years ago Louis Marx and others attempted to sterilize musts by heat for the purpose of fermenting them with pure yeast. The results, while promising, were not completely successful, on account of the cooked and "rancio" taste of the wines made. These tastes were due to the imperfect appliances with which the experiments were made. Later, Rosenstiehl, starting from the known facts, that the cooked or raisin taste was due to heating the must too high and the consequent caramelization of a portion of the sugar, and the "rancio" taste due to the exposure of the hot must to the oxygen of the air, invented and patented a process of sterilizing the must at a low temperature and out of contact with the air. The first defect was remedied by heating the must three times to a comparatively low temperature, allowing an interval to elapse between successive heatings. This had the effect of killing all germs in the must as effectively as a single heating to a higher temperature. The second defect was avoided by keeping the must in an atmosphere of carbonic acid gas during the heating.

Rosenstiehl's method, while effective, was slow, and required complicated and expensive machinery. Later it was shown, principally by the researches of Kayser and Barba at Nîmes, that the object which Marx and Rosenstiehl had in view, the absolute sterilization of the must, is not necessary in ordinary wine-making; and further, that the absolute exclusion of the air during heating, which Rosenstiehl attempted, is also unnecessary. All that is necessary in the first respect is that the must shall be "pasteurized"; that is, heated to such an extent that all *active* germs are killed. If a few germs in the latent or spore condition are left, they are absolutely innocuous, as they can not develop in time to do any harm. Before they have multiplied sufficiently, the wine is made and safe from their attacks. It is possible, therefore, to eliminate the injurious germs sufficiently by one heating to a temperature too low to caramelize any sugar.

With regard to the "rancio," it was found that must or grapes could be heated as high as necessary without acquiring this taste, if the exposure to the air was not excessive or continued for too long. It has lately been found possible, by the addition of a little sulfite before heating, to almost do away completely with any danger of oxidation, even with considerable contact with the air, and at the same time to get a more complete sterilization at a comparatively low temperature.

Sulfiting.—A method which promises well for use in hot climates is one devised by Martinand and Andrieu. It consists of adding a certain amount of bisulfite of potash to the crushed grapes and the subsequent addition of selected yeast. The addition of the sulfite is sometimes spoken of as a "sterilization." It is doubtful if the amounts used are sufficient to actually kill all germs in the must, but they are sufficient to prevent them from developing for some time; and in the meanwhile the selected yeast has time to completely take possession and finish the fermentation.

There are three ways of applying this method. The first is to add sulfite to the fermenting grapes in two or three doses, and is practically identical with the method already described (see page 46) for moderating the temperature by the same means. The other two methods differ in that so much sulfite is used that ordinary yeast is paralyzed with the other germs. For this reason it is necessary to have a special yeast which is capable of acting in the presence of the amount of sulfurous acid introduced into the wine. Such a special yeast is procured by taking any good strong yeast and gradually accustoming it to grow in the presence of large amounts of sulfurous acid. This is done in one of two ways. The way recommended by Andrieu is to fill each of two 50-gallon casks one-third full of must sterilized by heating. In the must in one cask is dissolved .5 per mil. of potassium meta-bisulfite; that is, 1 ounce to 15 gallons. The must in the other is started fermenting by introducing a small flask full of pure yeast. As soon as the must in the second cask is fermenting well, 5 gallons of the sulfited must from the first cask is poured in. This will check fermentation temporarily, but in a few hours the yeast becomes accustomed to the sulfurous acid and fermentation commences again. As soon as fermentation is well reëstablished another 5 gallons is added; and a few hours later the remainder of the sulfited must. When the yeast is fermenting well after the last addition of sulfite, it is ready to be used on a vat of grapes. The grapes as they come from the crusher are sulfited with a dose of potassium meta-bisulfite equal to that to which the yeast has become accustomed, *i. e.*, .25 per mil., or 2 pounds to 1,000 gallons or 4 tons. This is sufficient to prevent all fermentation except that of the added yeast. A pure fermentation is thus assured.

The other method is to train the yeast in the fermenting-vat itself. This is done by adding a pure yeast to the grapes as they pass into the vat, together with one-third of the amount of sulfite which is to be used, *i. e.*, two-thirds of a pound to the 1,000 gallons. This is enough to retard but not to prevent fermentation. As soon as fermentation has well started, another third of the sulfite is added, and then the remainder when renewed fermentation shows that the effect of the second dose has been overcome.

All these methods have given excellent results in numerous cases, but the second and third, and especially the second, are much more effective than the first.

SUMMARY.

METHODS ADOPTED IN SOUTHERN FRANCE AND ALGERIA.

Modern wine-making in these regions has developed along different lines, and each region has adopted a different method of overcoming the difficulties connected with the making of dry wine in a hot climate.

In southern France these difficulties have been attacked principally by means which aim at making the raw material more amenable to the conditions and methods of manufacture which exist there. The successful production of dry wines, there, depends in a large measure on: (1) the planting of the Aramon, a vine which produces grapes of high acidity and low sugar; and (2) on the gathering of all varieties before they are perfectly ripe. While the trouble of incomplete fermentations are thus, to a great extent, avoided and a sound wine generally made, the result is not altogether satisfactory. During the epoch immediately following the destruction of most of the vineyards by phylloxera (1890–1899), the abundant crops of thin, watery wine were very profitable. Now, when the supply has caught up to or passed the demand, the price obtained for the wine is often below the cost of production. A very large proportion of the Aramon wines can not be marketed without blending with heavier wines, and in years when the crop is large the price falls very low. In 1904 large cellars sold their crops at less than 6 cents per gallon, and the average price was probably not much over that figure. The wine has to be blended with Algerian or Spanish wines, and the wine-merchant can afford to give but little more for it than for piquettes and sugar wines.

In Algeria the Southern French method could not be applied. There, even the Aramon often attains too much sugar to ferment out completely without aid, and the grapes ripen so rapidly in the hot autumn that it is impossible to gather them all before they are quite ripe. Moreover, in the hot weather which is often experienced during the wine-making season in Algeria, grapes, even with low sugar-content and high acidity, may fail to complete their fermentation. Even if the Southern French method were possible, it would be impracticable in Algeria, where it would always be unprofitable to produce light blending wines in competition with the Midi. The demand for Algerian wines is based on their capability of correcting the defects o the Midi wines, and, to retain their market, they must be alcoholic and rich in tannin, color, and extract. Some means, therefore, had to be found which would enable the wine-makers to ferment Alicante Bouschet, Carignane, and similar grapes with 22% to 26% of sugar. The only

method which has come into general use is that of keeping down the temperature with cooling machines. This, as already noted, has enabled them to produce sound, alcoholic wines, but the moderation of the temperature has entailed a loss in the valuable qualities of deep color and high extract. In neither France nor Algeria, then, are the present methods of manufacture completely satisfactory, and attempts at improvement are being made along all the lines discussed in this report.

On the whole, however, there is less loss from spoiled wine there than with us, and a consideration of the methods of French and Algerian wine-makers offers many suggestions of possible improvements in our own methods. In no region, however, are the markets, raw materials, and conditions of manufacture identical with ours, and we can not, therefore, copy exactly any methods however successful elsewhere. It is impossible, moreover, to point out any method or group of methods that can be adopted here with absolute certainty of success in all regions. It is possible, however, to point out certain methods which, if adopted, will certainly result in great improvement in many of our wines. The conditions of soil, climate and grape varieties in Algeria resemble ours much more than do those of southern France. The following short description of the most approved method of vinification in Algeria should be of interest. It was kindly furnished me by Dr. Roger Marès of Algiers, who is an expert authority on the subject:

WINE-MAKING IN ALGERIA.

At the beginning of the vintage the juice of some well-washed grapes is placed in a small, perfectly clean and sterilized cask, and the contents of a flask of pure selected yeast added. The cask is placed in a clean room where there is no danger of infection by bad germs from cellar, fermenting-room, or pomace heaps. The room is kept at a favorable temperature (65° to 75° F.).

When the must is in violent fermentation it is added little by little to the vat as it is being filled with crushed grapes. If the temperature of the grapes is between 77° and 86° F., fermentation commences immediately.

The fermenting grapes are stirred frequently, night and day, and the temperature watched. The fermenting must is cooled as soon as it rises to 97° or 100° F. The temperature should not be lowered below 86° F.

The wine should be perfectly dry in a few days.

Fermentation takes place in open vats not deeper than 5 feet 6 inches. It is best not to have them exceed 11 feet in diameter, or the workmen find it difficult to stir them from the sides. If made wider a plank is placed across the middle to support the workmen while stirring.

The vats are made of masonry covered with cement, and cost about 2 cents per gallon.

It is always best to have the fermenting-room about 100 feet from the storage cellar; with this arrangement fermentation takes place better in the vats and the wine keeps better in the cellar. The cellar should be placed on the windward side of the fermenting-room.

Deep fermenting-vats are no longer built, and where they exist they are only partially filled.

Pressing is usually done with screw presses, but occasionally continuous presses are used, especially before fermentation when white wine is made.

Stemming is generally practiced, but if the grapes are clean and sound only a part of the stems is removed.

The pressed pomace is used for the production of piquette by the sprinkling method. The extraction of the wine from the pomace by the Roos method of displacement is advisable, but has not yet come into practice.

Selected yeasts are used only for the first vats; for the following vats about fifty gallons of fermenting must is taken from a previously filled vat and added gradually as the crushed grapes come from the crusher.

This may be considered the most approved method of wine-making at present in use in Algeria. It differs from the method in most general

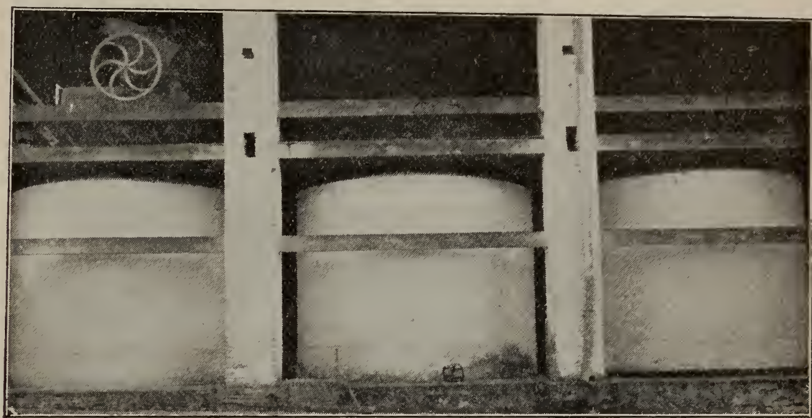

FIG. 9. Algerian amphoras used for fermentation.

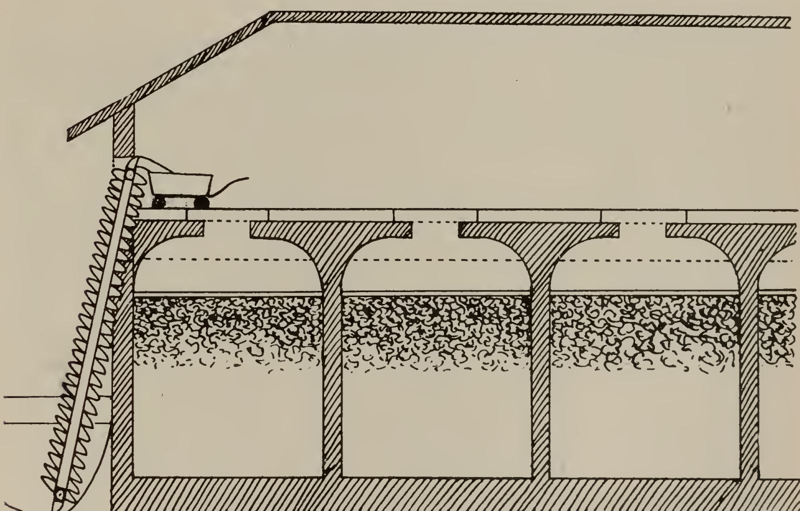

FIG. 10. Cross-section of an improved arrangement of amphoras for fermentation and storing.

use principally in the character of the fermenting-vats. The use of low, open vats and a separate fermenting-room necessitates an outlay which most Algerian wine-makers avoid by fermenting in the "amphoras" in which the wine is stored. These amphoras are constructed of masonry, concrete or brick, usually lined with glass. They resemble in shape

huge bottles, and hold from 1,200 to 12,000 gallons each. The diminution in the amount of spoiled wine in Algeria is undoubtedly due in some measure to the use of these amphoras, which it is possible to clean and sterilize with the greatest ease. They have many advantages over wooden casks or vats, especially for the handling of young wines. They can be cleaned in a few minutes simply by washing with a hose, and require no care when empty, as they do not shrink or become moldy, like wooden cooperage. There is no evaporation of the wine when they are filled, so that there is no loss of volume in keeping the wine, as with oak and redwood casks. They utilize the space in a cellar better, as they can be made of almost any shape and enable the wine-maker to store a much larger volume of wine under a given roof. In Algeria they have the further advantage of being considerably cheaper than oak casks. Their only defect is that they prevent the aging of the wine. This is, however, in Algeria an advantage, as the wine-buyers prefer a young, well-defecated wine which they can transport to France and age in cool cellars. The cost of these amphoras in Algeria ranges from 2 to 4 cents per gallon, depending on their size, shape, kind and amount of glazing, and the cost of transporting the material.

In comparing the relative cost of amphoras, oak casks, and upright vats, account must be taken of the differences in space occupied. Wine stored in round oak casks of 3,000 gallons capacity requires about 40 square feet of floor space for every 1,000 gallons. If stored in upright vats holding 10,000 gallons, of the form of the redwood vats commonly used in California, about 30 square feet is required per 1,000 gallons. With amphoras of 10,000 gallons capacity, 1,000 gallons can be stored in every 20 square feet. In other words, a cellar of one story with a floor space of 100 by 100 feet will hold about 250,000 gallons of wine in 3,000-gallon oak casks, 350,000 gallons in 10,000-gallon redwood vats, and 500,000 gallons in 10,000-gallon amphoras.

The cleanliness of the Algerian cellars visited was remarkable, and in strong contrast to many of the large cellars of southern France. The absence of woodwork and the liberal use of concrete make the work of keeping the cellars clean comparatively easy, as do also the simple and effective devices for handling grapes and pomace used by most wine-makers. The ease with which bacterial infection passes from cask to cask and from one vintage to another in hot climates has taught the Algerian wine-maker the necessity of thorough and frequent sterilization of everything with which the grapes or wine come in contact. Concrete vats and amphoras, if suspected, are rapidly and easily sterilized by swabbing with a 5% solution of sulfuric acid, but usually a simple washing with water is quite sufficient to keep them in good condition.

For the sterilization of wooden casks and vats of all sizes small steam

generators of a special form are much used both in France and Algeria, and are very effective. They are portable and so constructed that they produce dry steam superheated to over 500° F. under little or no pressure. They are useful in large as well as in small cellars, even where a

FIG. 11. Medium-sized wine-cellar and fermenting-room.

FIG. 12. Inside view of same cellar shown in Fig. 11.

steam boiler exists for other purposes. It is a great advantage to be able to sterilize casks at any time, and one of these small cask steamers can be heated up and used much more easily and rapidly than an ordinary steam boiler. They also have the advantage that they can not

explode, and the superheated dry steam they produce is much more effective in penetrating and sterilizing power than the pressure steam from an engine boiler.

Wherever separate fermenting-vats are used the tendency is to place them in a building separate from the storage cellar. This building is usually made very open, in fact is often simply a shed with open sides.

The figure on the cover of this bulletin shows the simple installation of a wine-maker near Berrouaghia, which may be taken as typical of small-scale wine-making in Algeria. It consists of an open shed covering three rectangular stone vats. The grapes are crushed into these vats and, after fermentation, are stored in the same vats, which are then covered with heads made air-tight with clay or plaster. The

FIG. 13. Open fermenting-room and shallow fermenting-vats of large cellar in the Sahel.

arrangement seems very primitive, but for the purpose is both cheap and effective. The small open vats are cooled off at night, so that only when the sirocco blows is there much danger of a hot fermentation. The wine is usually sold and shipped at the first racking, so that it is not exposed to the hot weather of the summer following the vintage.

Figs. 11 and 12 show a good example of a medium-sized cellar where from 10,000 to 20,000 gallons of wine are made. The sides of the cellar, which is for both fermenting and storing, are very open. The fermentation takes place in open brick vats and the wine is stored in brick amphoras. This cellar is in the Miliana region at a high elevation. The vintage is late and the weather not usually very hot during wine-making. The soil, the vineyards, and the wine in this district recall those of

Howell Mountain and similar situations in California. No cooling machines are used in either of these cellars.

Fig. 13 shows a good example of a fermenting-room of a large cellar in the "Sahel," the low range of hills running along the coast west of Algiers. Here the grapes become very sweet, ripen early, and the weather during the vintage is usually hot. The fermenting-vats are shallow, raised about 5 feet from the ground, and placed under an open shed. They are made of armed cement and have walls only about 4 or 5 inches thick. The method of wine-making is practically that advocated by Professor Marès, described on page 58. Cooling machines are used and every effort made to keep the temperature of fermentation low. As water is both scarce and warm, two cooling towers have been built to reduce the temperature of the water for the cooling machines. Fig. 14 shows one of these towers with the large fan used to produce the current of air necessary to cool the water.

FIG. 14. Cooling tower. Used in connection with fermenting cellar shown in Fig. 13.

CONCLUSIONS.

The main lesson of immediate practical importance to California wine-makers to be learned from these observations and experiments is the oft-repeated one of *cool fermentation.* It seems strange that in Algeria, where cool water is far more scarce than in California, the wine-makers should have been able to make the use of cooling machines a practical success, while here little or no progress has been made in that direction. The reason is to be found probably in a lack of a real appreciation of the need and use of cool fermentation among the wine-makers of the regions where dry wines are usually made, and of the difficulty of applying known methods in the hotter regions, where the cellars are nearly all of great size.

With regard to the first there is undoubtedly a very general lack of realization of the benefits to be derived from fermenting wines at a low temperature. A wine which attains a temperature of 95° to 100° F. during fermentation will never have the freshness, bouquet and general high quality of one which never exceeds 85° or 90° F. Even though the former ferments out completely and remains a perfectly sound

wine, its quality and especially its bouquet is injured, and the headiness of many California wines, and of wines from other hot countries, is undoubtedly due in great part to the high temperature of fermentation. The greater intoxicating effect of a California wine with 13% of alcohol over a Château Margaux with 11% can not be all ascribed to the slight difference of alcoholic strength. The variability of even the best brands of our California bottled wines is also in great part due to the lack of a more perfect control of the fermenting temperature. The California wines which a traveler finds in the Eastern States and in the hotels and dining-cars of England and the Continent are undoubtedly much superior to those he would have found there five or ten years ago, but they are still often very disappointing to one who knows how good they can be sometimes. The first step to be taken in establishing uniform and reliable brands of fine California wines is for the wine-makers to give their wines the uniform good quality which can only be obtained by fermenting every vat at a uniform and low temperature. This will render the work of the wine-blenders and handlers comparatively easy.

With regard to the production of common or bulk wines the problem is somewhat different. Here the main object is to produce a sound wine of good keeping qualities as cheaply as possible. The finer qualities of bouquet, freshness, and lack of headiness are of less importance. One of the essentials of cheapness is the production of heavy crops. Our cheap wines must be made, then, from heavy-bearing varieties of vines planted in rich soil. The vineyards of southern France, where common wines are made, produce from 8 to 10 tons per acre, and even as much as 12 to 15 tons as the average for whole vineyards. The vineyards of the Metidja Plain in Algeria produce as much. There are immense tracts of land in the Sacramento and San Joaquin valleys which are capable of producing equally large crops. The question is, can these crops be turned into good, sound, dry, red wines.

Innumerable tests at the California Experiment Station cellar prove that good, sound, dry wines can be made from grapes grown in rich, irrigated and alkaline soil in Fresno and Tulare. The experiments detailed on page 25 even show that wines of high quality can be made from such grapes. There is nothing, therefore, in the nature of the grapes themselves which will prevent the manufacture of good, dry wines in the great central plain of California. It remains to be seen whether a practicable method of wine-making can be devised which will overcome the difficulties which have so far prevented the production of such wines there.

The most promising direction in which to look for such a method is at present in line with the experiments of Barba, and the Berkeley Experiment Station. The method in short that offers an almost practical certainty of attaining our object is the following:—

1. Heating the crushed grapes to a temperature and for a time sufficient to extract the necessary color, tannin, and body.

2. Immediate separation of the must and cooling to 85° F.

3. Immediate fermentation of the must at a temperature not exceeding 90° F.

This is not to be understood as a recommendation of this method for immediate introduction into any cellar. The present status of the method is this:

1. It has been shown, both in California and in France, that it is possible, when working with small quantities, to attain the object in view by this method.

2. The method has been used with success in France in the whole output of a cellar manufacturing 75,000 gallons of wine in a season.

It remains now to be seen whether the method can be made practicable for California conditions. A careful study of these conditions has left little doubt in my mind that it can, and the failure of all other methods that have been tested so far makes it very desirable that it should be given a thorough trial. There are numerous details of the method which have to be carefully investigated, but none of them offer any apparently insuperable difficulties.

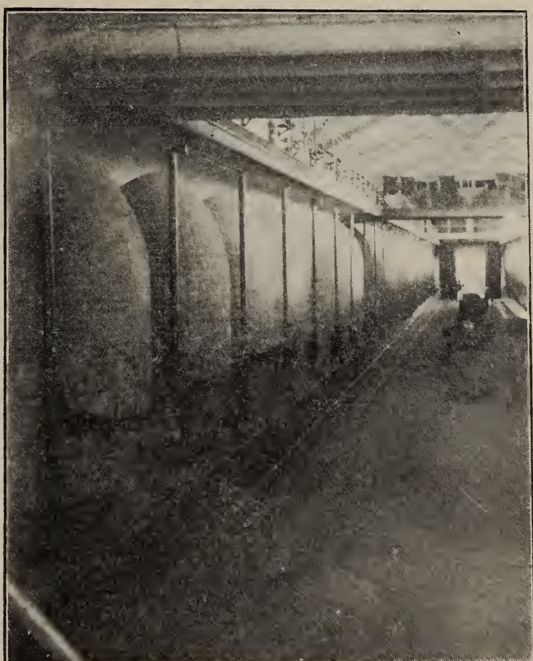

FIG. 15. Brick amphoras in a large cellar in Algeria.
This form is being abandoned, on account of the difficulty of making the vats strong enough when large.

FIG. 16. Amphoras in one of the largest and most modern cellars in Algeria.

FIG 17. Top view of the amphoras shown in Fig. 16.

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